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THE RECOGNITION OF FAULT SCARPS

ELIOT BLACKWELDER
Leland Stanford University

ABSTRACT

Fault block mountains have long been recognized in the genetic series of land forms. Physiographers now distinguish fault scarps from fault-line scarps or erosion scarps. The criteria for recognizing these two kinds of scarps are considered in this paper for the purpose of reaching a better understanding of their application and significance. It is shown that many of the features which are commonly regarded as evidence of fault scarps are generally possessed also by fault-line scarps, which are formed by differential erosion on previously faulted substructures.

GENERAL CONDITIONS

Much has been written about fault scarps, and many features have been diagnosed as such. The mountain ranges of Utah, Nevada, and adjacent parts of western United States have been interpreted as young or maturely dissected fault blocks. Hence the common phrase, "basin range topography." It is the general opinion that the major topographic features of that region are great earth blocks, raised, lowered, or tilted, although notably modified by erosion and deposition. However, it has been shown that many of the basins and ranges are the results of erosion upon a rock foundation that is affected by older faults. By a few geologists the fault-block theory as a whole has been challenged.

The disagreement seems to be due largely to an uncertainty regarding the criteria for recognizing fault scarps. Very few geomorphologists are prepared to distinguish a fault scarp from bold

escarpments of other origins. Obviously, one cannot distinguish one kind from the others until he understands the characteristics of all.

During the latter part of the nineteenth century, when fault scarps were being much noticed in connection with the exploration of western United States, insufficient distinction was generally made between geologic structure and topography. Mountains had been supposed to be chiefly constructional features, such as anticlines, volcanoes, or uplifted fault blocks, somewhat modified by streams in their first cycle of erosion. It was not yet widely admitted that most mountainous regions have been worn down to low hills or plains repeatedly, and hence that the topographic features produced by the original deformative movements have long since been effaced. The idea that the present topography of the continents (outside of certain young orogenic belts) is due largely to the differential erosion of rocks of heterogeneous lithology and structure, although known to the Arabs in the tenth century, is even today not recognized by all geologists.

Early in the twentieth century the previous view was generally abandoned by geomorphologists in favor of the theory that many, if not most, mountain ranges are not constructional, but destructional, forms. With this has come the conception that many scarps which are bounded by ancient faults have been produced, not by the dislocation itself, but by the later differential erosion. Spurr (1901, p. 231) called these features "erosion fault scarps"; but Davis' (1913) term, "fault-line scarp," meaning a scarp etched out along an old fault line, has been generally adopted by American physiographers. Still more recently, Cotton (1922, p. 171) of New Zealand, and others in the United States, have described "composite fault scarps" and other subdivisions of the two main classes. Scarps due to distributive faulting, or step faulting, in Nevada and California have been discussed by Louderback (1926). Lawson (1915) and more recently Davis (1925) have analyzed the processes and cycle of destruction of a simple original fault-block mountain by erosion in an arid climate.

In spite of all this progress, however, there is still much confusion regarding the interpretation of fault topography. Even in some of the most important papers on the Basin Ranges since 1910, much

evidence has been marshaled to show that the base of the scarp in question is associated with a structural fault. In establishing this point the authors evidently supposed they had proved that the scarp was due directly to dislocation, apparently not having realized that faults are necessary accompaniments of both fault scarps and fault-line scarps, and that hence the vital problem is not merely the faulted

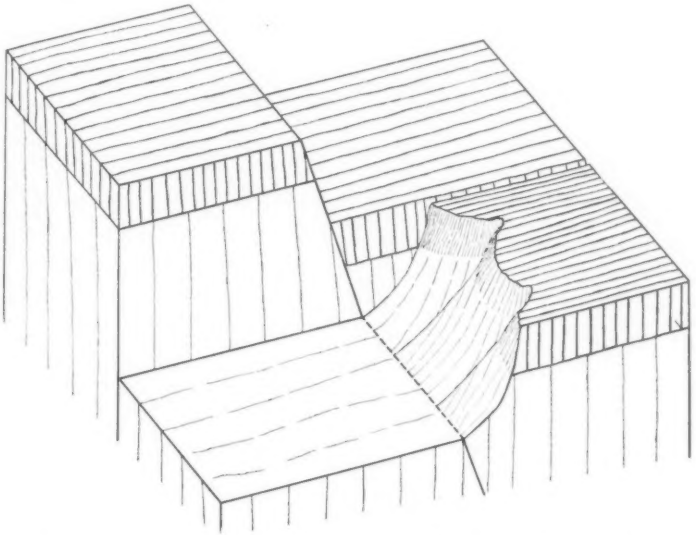

FIG. 1.—Diagram of fault scarp and fault-line scarp (after Cotton). A massive resistant stratum resting upon soft material has been dislocated, thus forming an uneroded fault scarp. A later stage is shown in the foreground, where erosion has reduced the upthrown block to base level, leaving an obsequent fault-line scarp on the downthrown side.

nature of the substructure, but the origin of the modern topographic form.

Furthermore, there is much disagreement as to the meaning of the term "fault scarp." In order to ascertain how the word is being currently used, the writer recently sent letters to about forty prominent physiographers and field geologists in various parts of the world. Replies to these letters show that on the one hand a few geologists would limit the term "fault scarp" to the initial cliff, whose face is part

of the fault surface itself. Since uneroded cliffs of this kind are very rare, except perhaps under the sea, and are usually of slight relief, the term could hardly ever be applied to existing mountain ranges. At the other extreme there are a few geologists who would call any scarp a "fault scarp" if it is bordered by a fault, even though the direction in which the cliff faced has been reversed by prolonged erosion through several cycles. However, the replies show that about three-fourths of the qualified physiographers in the United States have adopted, and use with considerable unanimity, the classification proposed by Davis (1913), who recognizes initial fault scarps, youthful fault scarps, mature fault scarps, resequent fault-line scarps, and obsequent fault-line scarps. The majority of these physiographers would cease to apply the term "fault scarp" after the block has been so much eroded that the front is no longer abrupt, but is a complex of branching spurs and ravines. Beyond that stage they would speak of the feature as a fault-block mountain in a mature or old stage of erosion. If a scarp should be subsequently etched out in relief by differential erosion, they would call that a fault-line scarp.

In spite of the fact that there are all gradations between the varieties which have been mentioned, and in spite of the complications that may be induced by the revived uplift of an otherwise old fault block or by the further etching out and heightening of a true fault scarp by erosion along its base, it should in general be possible to distinguish rather definitely between hills and mountains, the distinctive forms of which are due to faulting modified by erosion, and others which are due to erosion on a faulted substructure. In regions of active diastrophism, such as the Pacific coastal belt of the United States, the former type seems to be common; but in regions of crustal stability the second type is almost the only one found. Considering the world at large, the writer agrees with Spurr (1903) that "erosion fault scarps [fault-line scarps] are much more common than fault scarps." Davis (1913, p. 209) has expressed a similar view in other terms.

Without regard to its origin, a scarp of any kind may be defined as an abrupt slope, of notable length, contrasted with gentler slopes or plains about it. It is an abbreviation of the word "escarpment,"

which in turn is a French word borrowed from the military engineers and meaning a steep slope, like the side of a fort. Among the mountains the relief of which is due to faulting, it is advisable to distinguish slopes which are still truly scarps from those which have lost the abruptness that is the essential attribute of a scarp. It would be a misuse of the empirical term to call a low, straggling mountain range with broadly extended gentle spurs a "scarp" in any case, since the essential requirement of steepness is not fulfilled.

In the following pages, therefore, the writer will discuss only those topographic features that are actual scarps with conspicuously linear bases marked by important structural faults. Those which owe their relief directly to differential movement of the crust will be called "fault scarps," even if they have been notably scarred by erosion. Those which owe their present relief to the wearing down of weak rocks, leaving resistant rocks standing out in relief, will be called "fault-line scarps." The former are necessarily in the earlier stages of the present cycle of erosion; but the latter are generally in the middle or later stages of an erosion cycle subsequent to the faulting. As pointed out by Cotton (1922, p. 170), fault-line scarps may in rare cases develop in the later stages of the first erosion cycle, where structural conditions happen to be nicely arranged to that end.

True fault scarps (or tectonic scarps) are most easily recognized in the initial stage of erosion. As denudation progresses they gradually lose their distinctive characteristics to such an extent that, before the cycle is half completed, it may be almost impossible to recognize them. Furthermore, since nearly all great scarps are the products of intermittent small uplifts, the intermediate effects of erosion may be such as to keep the rising block in a maturely dissected state continually. For these reasons young and easily recognizable fault scarps are much less common than is generally supposed.

On the other hand, fault-line scarps develop best in the mature or post-mature stages of the erosion cycle. They may be non-existent in the very youthful stage, and theoretically they should be effaced before the end of the cycle. However, since they are most prominently brought out into relief during that long intermediate stage in the cycle which has been reached over the greatest areas of

the continents, it is not surprising that fault-line scarps appear to be much more common and widespread than fault scarps.

At present the thing most essential for progress in this study seems to be an agreement among physiographers as to what criteria may be used to distinguish fault scarps from fault-line scarps, and as to the relative values of such criteria. Therefore the writer has listed below, first, the joint attributes of both kinds of scarps; second, the criteria that are conclusive or at least strongly indicative of true fault scarps; and third, those that serve to distinguish fault-line scarps from the former. Criticism of, and additions to, these three lists are solicited.

FEATURES COMMON TO BOTH KINDS OF SCARPS

1. *Abrupt and often imposing front.*—The sight of a long, straight mountain slope rising prominently from the adjacent plain is enough in itself to satisfy some field geologists that the slope is a fault scarp. This is especially true of those who have not come to realize that in desert regions steep slopes are the normal result of stream erosion even to the stage of old age, as has been ably explained in recent years by Lawson (1915), Bryan (1922), and Davis (1925). To conceive of the foundation of the plain and the top of the mountain as two parts of the same surface, now dislocated, seems to tax the mind less than to imagine the vast amount of erosion needed to reduce most of the region to a lowland thousands of feet below the original surface. Nevertheless, some fault-line scarps that have been identified by critical study are as high and as abrupt as most true fault scarps. The only necessary condition is an unusually massive and resistant formation exposed to erosion along a fault contact with a very easily eroded formation. The latter may be reduced to a plain before the former has lost the aspect of early youth.

It seems necessary to conclude, then, that, although many fault scarps are steep, the steepness of a scarp is not strong evidence that it is of tectonic rather than erosional origin.

2. *Presence of a marginal fault.*—This is a necessary feature of both fault scarps and fault-line scarps, and hence indicates merely one or the other. Yet many pages in the literature of the subject have been devoted to proving the existence of a fault, on the tacit assumption that such proof would be conclusive evidence that the

scarp was of tectonic origin. Many of the following criteria that are most commonly employed in diagnosing fault scarps prove nothing but the existence of a fault, whether young or old. The chief indexes of a fault that may be observed along the scarp are: (*a*) *Presence of fault-breccia, slickensides, etc.* These also merely prove that there is a fault. Davis (1888), in describing the old fault-line scarps of the Triassic Basin of Connecticut, has noted their presence. (*b*) *Truncation of strata and other geologic structures along the scarp.* Like the last, this is quite as characteristic of a very ancient fault as of a young one. Hence it does not assist in distinguishing a fault scarp from a fault-line scarp.

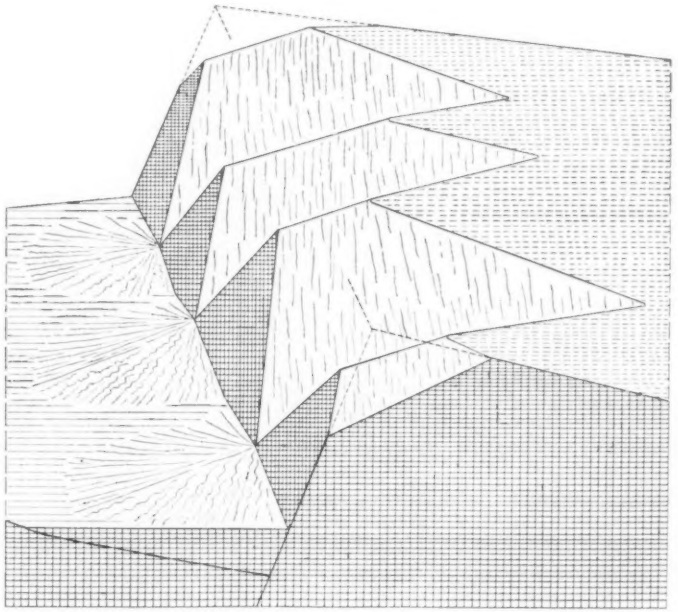

FIG. 2.—Diagram illustrating the origin of triangular facets during the erosion of a fault block mountain (after Davis).

3. *Triangular facets on the ends of short spurs.*—The triangular facet is one of the most commonly cited indicators of a fault scarp. It has been rather generally inferred that the more or less definitely

triangular facets which terminate the spurs along many scarps are remnants of the fault surface itself; that they have been isolated from each other by the carving of deep transverse ravines; but that the facets themselves have been only slightly marred by erosion. The actual measurement of the frontal slope of a large number of these facets, by Louderback, the writer, and others, shows, however, that their inclination is generally between 20 and 30 degrees, and rarely so much as 32 degrees. On the other hand, where the fault plane itself is actually exposed in the rock, its dip is commonly between 50 and 90 degrees, and rarely less than 40 degrees. These facts indicate that the observed triangular facets are usually not remnants of the fault surface, but have been worn back to the usual slope of equilibrium that is common to mountain sides of various origins.

Inasmuch as excellent triangular facets have developed on many proved fault-line scarps and also on other scarps not connected with faulting (Lahee, 1923, pp. 279–80), it will hardly do to urge the presence of triangular facets along the base of a range as strong evidence of a fault scarp. It is merely compatible with such an explanation. Facets may be due either to faulting plus erosion, or to erosion upon a very weak formation lying with steep contact against a very resistant one. It is probably true, however, that very prominent facets are more commonly associated with fault scarps than with others. Wave erosion along their bases has accentuated many such facets in the Great Basin.

4. *Linear base, with alignment of facets.*—This also is a necessary result of the presence of a fault, whether it be young or old.

5. *Sharp V-shaped canyons, with streams flowing on rock channels down to the very fault line.*—Although these have been cited by Davis (1913) as evidence of a fault scarp, they are produced under the same conditions as facets on the spurs, and like them occur in both types of scarps.

6. *Increase in the stream gradient as the fault line is approached from upstream.*—In common with the formation of triangular facets and sharp V-shaped canyons, this is one of the necessary results of either the more rapid lowering of the channel on soft rock in contact with hard, or the increase of the relief of a block during

the faulting. The effect on the stream is similar in either case. The next item is only an extreme case of the same thing.

7. *Hanging valleys on the face of the scarp.*—As described by Russell (1905, p. 78) and others, the rapid uplift of a fault block may leave ravines hanging above the base of the scarp. It is not so generally understood that similar features are developed upon fault-

Fig. 3.—Fault scarp southeast of Deep Springs Valley, eastern California. The mountain consists of granite. The short steep spurs end in triangular facets, the bases of which form a gentle curve in ground plan. Narrow V-shaped canyons have abnormally small alluvial fans at their mouths. Also the lowest part of the valley, now occupied by a salt pan, is situated at the base of the scarp instead of in the middle of the basin.

line scarps by the rapid wearing down of the weaker side. Such features are probably more common on true fault scarps than on fault-line scarps, for in the latter case they must depend for their existence upon rapid denudation and great contrast between the lithology of the two adjacent masses. Such conditions are illustrated by the fault-line scarp 15 miles northeast of Bakersfield, California.

8. *Range unsymmetrical, having its crest nearer the fault line than the middle.*—This also is a normal result of the rotation of a fault

block or of the differential erosion of a faulted mass in which one block of assymetric shape is more resistant to erosion than the others. Massive lava flows, tilted in sequence with soft sedimentary strata, have been sculptured into such ridges in many places.

9. *Springs (hot or cold) along the base of the scarp.*—Russell (1885) and others have regarded the presence of hot springs not

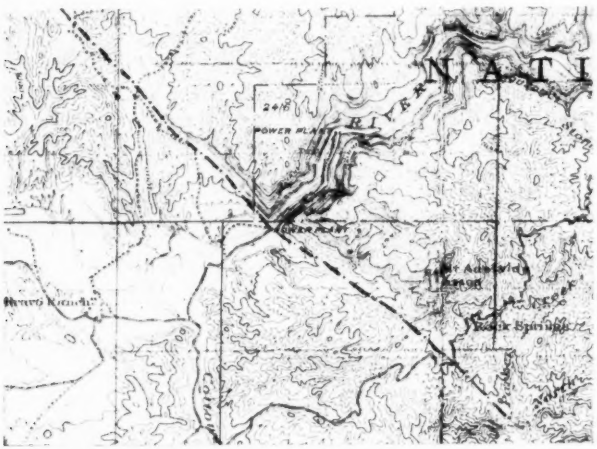

FIG. 4.—Contour map of the fault-line scarp at the mouth of Kern River Canyon, northeast of Bakersfield, California. The scarp is 1,200 feet high near the river, but decreases to almost nothing within 3 miles in either direction. The fault itself, with a displacement of several thousand feet, persists. The scarp is marked by exceptionally smooth triangular facets, a sharp V-shaped canyon, and small hanging ravines. There is no accumulation of alluvium on the downthrown side. Massive granite is in contact with weak Miocene sediments.

only as evidence of the presence of faults, but of the recency of movement along them. While there is good evidence that the waters of both the hot and the cold springs commonly rise along fault fissures, such springs are found, not only in regions of recent, but ancient, faulting. In this connection it is interesting to note that Russell found, along a very recent fault scarp in the alluvium near Summer Lake, Oregon, many large springs, nearly all of which were cold. On the other hand, the hot springs at Thermopolis, Wyoming, Hot Springs, Arkansas, and many others are in regions

of ancient faulting. Hence it seems probable that these springs are due to the obstruction of normal underground drainage channels by faults, whether young or old.

10. *Occasional weak earthquakes.*—Earthquakes are often cited as evidence of active crustal dislocation. It is a fact, however, that in the vicinity of many fault-line scarps there are frequent tremors and occasional slight earthquakes. If dislocation is still continuing in such regions, its rate is so slow that its effects are quite overpowered by the action of erosion.

11. *Landslides.*—Although these are especially favored by strong earthquakes, they are also commonly induced by the oversteepening of the slope of a fault-line scarp, and are prevalent in rugged mountains that are devoid of faults. Their presence along erosional scarps is therefore not surprising, and they do not constitute strong evidence of recent faulting.

The foregoing list contains some of the criteria which are commonly used for the identification of true fault scarps. It is important to understand that, although most of them serve to arouse a justifiable suspicion of recent faulting, they do not afford positive evidence of such an origin.[1] By stripping a weak formation from an underlying resistant one, in a faulted sequence, the processes of erosion may exhume a surface that simulates very closely the forms produced by crustal dislocation. Under suitable conditions this eroded surface exhibits splintered scarps, steps, facets, V-shaped canyons, a linear base, truncated folds, and hanging valleys, as well as other features that are also induced directly by faulting.

POSITIVE EVIDENCE OF FAULT SCARPS

1. *Poor correlation between rock resistance and surface form.*—If the scarp-fronted mountain consists of easily eroded rocks, it cannot be a fault-line scarp; for the latter depends for its origin solely upon the fact that its material is such as to survive erosion. Some of the fault scarps near Hollister (R. Willis, 1925), Redlands, and Mecca, in the California Coast Ranges, in which nearly unconsolidated Pliocene sedimentary deposits form the bulk and front of

[1] In a book that contains one of the clearest brief expositions of the subject extant, Lahee (1923, p. 225) has expressed the same general idea.

the ridge, must be fault scarps, because they are based by faults and afford but little resistance to erosion.

When available, this criterion is usually decisive; but on account of the fact that older rocks are commonly more resistant to erosion, an uplifted block, revealing older terranes than the downthrown block, is likely to consist of harder rocks merely for that reason. Hence this criterion is generally not available.

FIG. 5.—West front of the Panamint Range, in southeastern California. The view looks northeast toward Emigrant and Townsend passes. The central part of the range consists entirely of Pliocene (?) slightly indurated gravel or fanglomerate. The higher mountains on either side reveal Paleozoic rocks. The small terrace in the alluvial slope along the base of the range is a fault scarp, apparently of late Pleistocene age.

2. *Rift features.*—The undrained troughs, ponds, peculiar wedge-shaped hills, and other features which have been recognized under this name by many students of the San Andreas fault zone (Lawson, 1908; R. Willis, 1925) in California are rather distinctive, and with due care they may be used to recognize topography influenced by tectonic dislocations. But unfortunately they also are seldom present.

3. *Alluvial deposits on the downthrown block thickest near the fault line.*—In block faulting it may well happen that the depressed

side of a rotated block is carried thousands of feet below the local base-level of erosion. In that case alluvial deposits of corresponding thickness will form a wedge-shaped mass which is thickest on the side toward the fault. This should be conclusive evidence, but unfortunately it is seldom available; and even when offered it is generally open to grave suspicion. Deep wells are almost the only source of information; and well records are generally untrustworthy, because the drillers are not lithologists and are unable to distinguish between unconsolidated Recent or Pleistocene alluvium and weakly cemented Tertiary beds that may have been deformed long before the present topographic features existed. In drilling a well recently in Utah, thick beds of tilted Miocene tuff were recorded as "blue clay and sand" and were later interpreted by an unwary geologist as being Quaternary lake deposits. Hence such records are of little value unless they are supported by authentic samples examined by a competent geologist.

A sheet of alluvial materials, 200–400 feet thick, may be the result of a mere climatic change, like the glacial period. Such deposits may form a thin veneer over a plain developed by erosion during the formation of a fault-line scarp, as inferred by the writer (1915) in the case of Jackson Hole in Wyoming and Cache Valley (1925) in northeastern Utah.

4. *Lake, or "sink," close to the scarp base.*—When a fault scarp facing upstream interrupts a transverse valley, a lake may be formed along the base of the scarp (Lahee, 1923, p. 223).

Even where the fault is not transverse to such a valley, the rotation of the depressed block commonly leaves a low area at the base of the scarp, and it may be occupied by a lake. Such rotation is a common accompaniment of fault movement.

Davis (1925, p. 390) regards the position of such lakes as a particularly useful criterion in the Great Basin region; but it is not without exceptions and should be used circumspectly. It is closely akin to the next item.

5. *Alluvial fans abnormally small.*—The same observer has noted that abnormally small fans at the mouths of canyons are characteristic of certain fault scarps. It is argued that the sinking of one side of a tilting block would gradually carry down with it the alluvial

deposits made by streams descending from the scarp of the adjacent rising block. On account of repeated sinkings, the visible upper parts of the fans made by such streams would not be comparable in volume with the canyons in the rising block from which they were derived.

Although this criterion cannot be used as an empirical rule, it should be significant in connection with careful regional studies in which all the local conditions are duly considered. Removal of the fans, rather than the burial of them, is an alternative not to be overlooked.

6. *Frequent severe earthquakes.*—These show that diastrophic movement is actively going on; and it is only such relatively frequent dislocations that outstrip the erosional processes and produce notable fault scarps. In Shensi and Kansu provinces, China, many destructive earthquakes have occurred along the bases of several of the lofty scarps of the region, and the historic records extend back some 3,000 years from the present time. Such evidence strongly indicates that the mountains are young fault blocks still actively rising.

7. *Displacement of an older topographic surface.*—Theoretically, this is one of the best indicators of a fault scarp; but practically the application of it is fraught with difficulties and hidden dangers that are seldom considered. Before such an observation can be admitted as evidence it is first necessary to establish the fact that the two fragmentary surfaces—one on the upthrown, and the other on the downthrown, block—were formerly continuous. As emphasized by Willis (1925, p. 361) this in itself is usually a difficult problem. The downthrown remnant is likely to be concealed by younger deposits, and hence not open for correlation. Also, the surface in question may not be peneplain, but a surface determined by a hard layer and therefore in the nature of a denuded dip-slope. Again, a remnant of an old topographic surface may be preserved at high altitude on the resistant mass of a fault-line block and may be erroneously correlated with a plain subsequently developed by erosion at a lower level in the following cycle of erosion. For these and other reasons the criterion, although valid in theory, is in most cases a treacherous one to apply, and hence requires a more careful regional study than is usually made.

8. *Recent or late Pleistocene formations dislocated.*—Since there is

much to indicate that the topographic features of Tertiary and even of early Quaternary landscapes in general have been almost entirely destroyed by erosion, fault scarps of pre-Pleistocene age have generally been effaced. Their places have been taken in some cases by fault-line scarps subsequently developed. However, if it can be shown that formations which are younger than the major topographic features have been broken, then the associated scarps should be fault scarps. If it is even known that the general region is one of strong Pleistocene deformation, there is an inherent probability

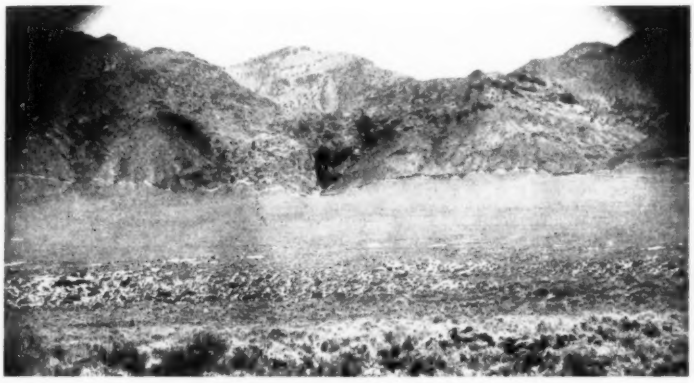

FIG. 6.—Recent scarplet along the west base of the Sonoma Range, in central Nevada. This rent was made at the time of the 1915 earthquake. It extends for about 40 miles, and has a relief of 10–20 feet. In many places instead of cutting the alluvial fan it intersects the rocky spurs themselves.

that any mountain scarp will prove to be a fault scarp; but such an inference would require verification by other means.

Many instances of dislocated alluvial fans and even glacial moraines have been reported from the Great Basin region. They are generally small features, 10–50 feet high, and ordinarily escape the notice of anyone who is not a trained geologist. They have a superficial resemblance to alluvial terraces, but are readily distinguished from the latter in most cases. Some of the scarps have been formed at the times of historic earthquakes, and a careful examination of others shows clearly that they are true dislocations.

9. *Basal scarplets.*—Along the bases of many of the steep

mountain ranges of western United States there are low cliffs evidently younger than the general slope. To these Davis has applied the convenient term "scarplet." The best instance known to the writer is afforded by the series of scarplets 10–25 feet high along the west base of the Sonoma Range in north-central Nevada. They have been described by Jones (1915) as having been formed at the time of the 1915 earthquake. Such scarplets are rather generally regarded as proof of the intermittent dislocation of two fault blocks. As developed in the arguments of Gilbert (1890), Lawson (1912), and Davis (1913), the presence of such a scarplet along the base of an abrupt mountain front is strong evidence for regarding the latter as a fault scarp.

Nevertheless there are considerations that tend to weaken the force of such evidence, and these considerations have not received merited attention. Many great fault scarps show no trace of basal scarplets. In other cases the basal scarplets diverge from the range and run out into the plain at considerable angles from the range front. In some places the scarplets cross valleys and even maturely dissected hills that have no scarps. Among the scarplets southeast of Salt Lake, Utah, and in the northern part of the Panamint Valley of California, some face the mountain front and hence can hardly be indicative of a subsidence of the plain or a rise of the mountain block. Scarplets are produced around the margins of landslips and wherever the settling or condensation of unconsolidated material takes place. In the case of thick Pleistocene deposits in an intermontane valley, such settling would be apt to take place along the base of the adjacent range. It seems evident from these facts that the basal scarplets need a more thorough and critical study than has yet been devoted to them. Until a better understanding of them has been reached, it may be unsafe to accept them as proof that the mountain fronts with which they are associated are young fault scarps.

10. *Warped terraces in the canyons.*—On a rotating block, stream terraces may be developed during pauses in the tilting movement. These terraces should afterward be found along the sides of the valleys, and they should have abnormal gradients. The terrace in West Walker River Canyon, east of Wellington, Nevada, seems to afford

an illustration. Another has been observed in the Alabama Hills west of Lone Pine, California.

11. *The actual fault plane identified as forming part of the scarp face.*—While this is theoretically a valuable criterion, and has been used particularly by Gilbert (1917), many mistakes have been made in the application of it, and it is seldom of much practical value. The only reliable cases known to the writer are those identified in connection with recent earthquakes, such as the great Yakutat Bay shock of 1899 (Tarr and Martin, 1906). Generally weathering and erosion destroy the original fault surfaces soon after they are brought to view.

The important thing is to distinguish cases where the fault surface has been revealed by recent dislocation from those in which an old fault surface has been exposed by denudation. The writer has carefully examined the locality near Ogden, Utah, pointed out by Gilbert, and has found that the slickensides dip in various directions with reference to the range front and are probably due to compression. In that case they are perhaps of ancient date and related to the post-Cretaceous deformation of the strata. As evidence of recent faulting such phenomena must therefore be regarded with suspicion.

On reviewing the foregoing criteria for true fault scarps it will be observed that some of them are seldom available and that others are decidedly untrustworthy, except under the most favorable circumstances. These are doubtless the chief reasons why the reliable identification of a fault scarp is a difficult matter, generally calling for the greatest care, comprehensive field study, and the analysis of complex data. In many instances the decisive evidence is entirely lacking. In others the requisite analysis has not been attempted.

FEATURES DISTINCTIVE OF FAULT-LINE SCARPS

1. *Scarp situated on the downthrown side of the fault.*—This condition is easily observed and is conclusive; but it is true only of obsequent fault-line scarps, which are much rarer than the less distinctive resequent type. Good examples are found in the scarps of Cambrian sandstone faulted into older schists in the Llano uplift of central Texas. Since old rocks that form the upthrown blocks are

generally more indurated and resistant to erosion than the younger formations of the downthrown side, large obsequent scarps are rare.

2. *Close correlation between rock resistance, structure, and topography.*—This principle has been thoroughly explained by Davis (1913) in an elaborate paper on fault scarps and fault-line scarps. The essential facts are that the scarp is high and abrupt where the lithologic contrast is greatest and erosion most active, is more subdued where the rocks are somewhat less resistant or erosion less active, and disappears entirely where the contrast between the dislocated blocks is merely one of age and not one of resistance to erosion.

This is not only a strong criterion, but it is applicable to nearly all cases. Therefore it is the most useful of all. Good illustrations are afforded by Mount Holyoke (Davis 1913, p. 210) in Massachusetts, the Front Range at Colorado Springs, Colorado, the Teton Range (Blackwelder, 1915) in western Wyoming, the Hurricane fault in northwest Arizona (Davis 1913, p. 210), and the scarp at the mouth of Kern River Canyon in California (Blackwelder, 1927).

3. *The trace of the fault crosses the lateral spurs instead of limiting their ends.*—In the Bear River Range, north of Logan, Utah, the main body of the mountains is composed of Paleozoic dolomites and quartzites, but on their western flank the latter are separated from Tertiary conglomerate, sandstones, and tuff by a fault of great displacement. The conglomerates offer some resistance to erosion, although they are much weaker than the massive dolomites; but the beds of ash, tuff, and marl are very easily eroded. In the front of the range, therefore, the conglomerates form the lower parts of the spurs descending from the crest of the range, and the great fault separating the rocks of the two ages can be traced, with but slight topographic expression, across the entire series of spurs. The plain is underlain largely by the tilted beds of soft rhyolitic tuff veneered with lake deposits. Such relations indicate that the range is due to the superior resistance of its mass as compared with the adjacent blocks, but that the faulting antedates the existing topography. Bailey (1927) has recently diagnosed this range as a fault scarp; but, in the writer's opinion, he has brought forward no evidence against the view that it is a fault-line scarp.

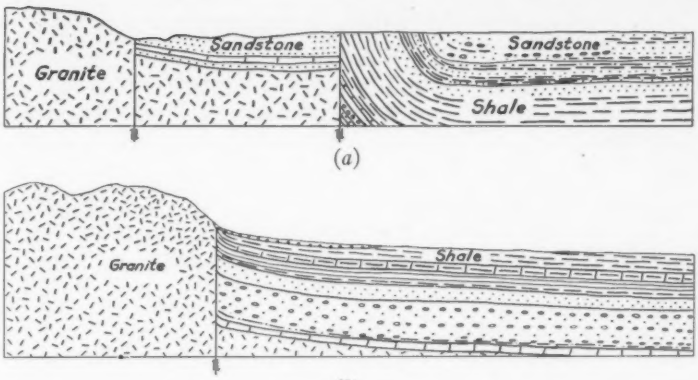

FIG. 7.—Two cross-sections of the fault-line scarp along the Front Range, in Colorado: (*a*) seven miles south of Colorado Springs, (*b*) six miles north of Palmer Lake. In both cases the weak sedimentary strata have been eroded down to a plain, leaving the massive granite standing as a bold scarp (adapted from folios of the United States Geological Survey).

FIG. 8.—West front of the Bear River Range in northeast Utah, looking southeast from Franklin Butte. The range consists of strongly tilted Paleozoic quartzite and dolomite. The foothills consist of Miocene (?) conglomerate, sandstone, and other sedimentary deposits. Between the two runs a steeply inclined fault of several thousand feet displacement. It has no topographic expression except that which is caused by the difference in erodability of the formations on the upthrown and downthrown sides, and it runs southward into a mountainous area where all semblance of a scarp is lost, although the fault continues.

4. *Proof that the fault movement was pre-Pleistocene.*—In the case of the Hurricane fault in northern Arizona, Davis (1913, p. 210) and others have shown that the fault was base-leveled and the trace then covered by a Miocene lava flow which has not subsequently been dislocated. Differential erosion along this old line has, however, largely reproduced the scarp. There are many such cases, but few so clearly established.

5. *Little or no alluvial deposit on the downthrown block.*—In the opinion of Robin Willis (1925, p. 362), "erosion scarps" cannot be bordered by alluvial fans, except where climatic changes have disturbed normal conditions. On the east side of the Colorado Front Range, near Colorado Springs, the beveled Cretaceous shales are broadly exposed in the plain at the foot of the range, with only a small amount of detritus along the fault line itself. Similar conditions are found in Sheep Mountain[1] and the adjacent Medicine Bow Range in Wyoming. In all of these cases the ranges are bounded by faults of thousands of feet displacement; the slopes are very abrupt and are marked by triangular facets, linear bases, and other putative evidences of true fault scarps.

Nevertheless, this evidence must be used with due regard to special conditions; for in a case of recent faulting, if both blocks had gone up with reference to general base-level, the upthrown block having merely been raised higher than the other, there should be no deposition of detritus on the latter. Widespread physiographic studies will generally serve to dispose of such questions.

6. *Superposed drainage.*—Where it can be demonstrated that the drainage is really superposed, this criterion is decisive. As an illustration, in the Red Creek district north of the Uinta Mountains in Utah, remnants of horizontal Tertiary deposits capping many surrounding summits show that the drainage across the district was superposed upon the level Tertiary beds that rest upon the highly folded strata beneath. At the fault contact between the very weak Upper Cretaceous shales and the intensely hard Algonkian metaquartzite, a well-defined fault-line scarp, 1,800 feet high, has been developed. The Llano district of central Texas and the Triassic belt of the Atlantic coastal states afford other examples.

[1] U.S. Geol. Survey Topographical Maps of Laramie and Medicine Bow quadrangles.

COMBINATIONS AND COMPLICATIONS

In the foregoing list there is a tacit assumption that the cases are relatively simple. A mountain block is elevated by a succession of rather frequent movements along a simple fault plane, develops a distinctive tectonic form, slightly modified by erosion, and is then left to waste away. Again, a region of faulted hard and soft rocks is quietly subjected to erosion, which brings the hard masses out in relief and thus produces, during the later stages of the erosion cycle, fault-line scarps and other topographic contrasts.

It will readily be admitted, however, that geologic histories are not usually so simple. Thus Gilbert (1917) inferred, regarding the Wasatch Mountain front in Utah, that there have been several periods of faulting; the latter were separated by long intervals of comparative quiet, during which deep valleys were eroded. In such a case fault-line scarp features might succeed true fault scarps and in turn be modified by younger fault scarps. The present result of such events would depend on the particular sequence and stages reached. Cotton (1922) has described from New Zealand composite fault scarps along which erosion has lowered the downthrown block to such an extent that the lower part of the front is now a fault-line scarp, although the upper part is a fault scarp. In three recent papers, Louderback (1924, 1925, 1926) presents an interesting and valuable discussion of the complexities of topography influenced by step-faulting as interpreted by him in northeast California and adjacent parts of Nevada.

This is not the place to attempt a full discussion of these and other modifications, but mention of them may serve to remind field geologists that the recognition of a fault scarp does not depend upon the blind application of a few convenient rules, but generally requires a critical analysis of complex data, among which there may appear to be conflicting elements which need to be reconciled. The necessary first step in making such an attempt is to realize that fault-line scarps are in general commoner than fault scarps, and that the former resemble the latter in most respects, although they are entirely different in origin.

Matters of internal structure on the one hand and of topographic form on the other must be carefully separated; and the same terms

should not be used for both categories. Many writers use such terms as "horst," "graben," and "fault block" indiscriminately for features of either structure or topography. No element in the situation has caused more confusion than the all-too-common failure to keep these two categories clearly separated.

CONCLUSION

In interpreting the origin of earth features it is important to distinguish between fault scarps and fault-line scarps. A fault scarp, or a fault block mountain, is a feature brought into relief by crustal dislocation and more or less modified by the erosive processes. A fault-line scarp, on the other hand, has been brought into relief by the differential erosion of weak and resistant rock masses separated by old faults, the original scarps of which had previously been erased. Combinations and alternations are possible.

It is essential to understand that erosion, in developing a fault-line scarp, may bring into view most of the topographic features commonly supposed to be characteristic of true fault scarps. For this reason one should approach such a problem with caution and should consider carefully the evidence used for the recognition of either type of scarp. Until the criteria shall have been better established, agreed upon by geomorphologists, and understood by field geologists, the casual diagnosis of any mountain front as a fault scarp should not be received with much confidence.

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ALTERNATIVE HYPOTHESES FOR CHANNELED SCABLAND. II

J HARLEN BRETZ
University of Chicago

SIMULTANEOUS DEVELOPMENT OF ALL CHANNELS OF THE SCABLAND PATTERN

A simple alternative to the flood hypothesis is that the main routes of glacial water across the plateau were sequential in operation. The writer has described the anastomosis as possessing ten or twelve channel heads on the edge of the glaciated tract. If the ice margin could be so shifted that only one or two of these operated at one time, making them sequential in development, the flood scheme would collapse. We would still have a remarkable assemblage of "anomalous, indeed unique, drainage features" and would still have to admit "the necessarily large volume of many of these streams." But catastrophism would be avoided.

An examination of this conception is not an office task. There are five critical places to be studied in the field: the glaciated plain and channel heads,[1] the divergences in the anastomosis, the convergences in this pattern, the Columbia Valley beyond the plateau system, and the non-scabland valleys entering waterways used by the glacial streams. Features in each of these places should record definitely whether or not the different routes operated simultaneously. By either hypothesis each type of place should have its own type of record. These will be considered in the order listed.

HEADS OF SCABLAND CHANNELS

Restudy of the glaciated plain north of the channel heads has shown that earlier statements concerning morainic records of the ice edge are correct. There are essentially none. There is moraine topography on Sunset Prairie just west of Spokane. Perhaps 40 or 50 hills of very bouldery till are scattered over 12–15 square miles.

[1] Pointed out by Dr. W. C. Alden.

The total relief does not exceed 50 feet. The height of separate hills rarely is more than 25–30 feet. When mapped, they are only a circuloid group surrounded by till with even weaker topographic expression. There seems to be no hope of mapping any shifts in the edge of the ice from this evidence.

North of Davenport, 25 miles west of Sunset Prairie (Fig. 7), the glaciated tract is deeply canyoned by tributaries to Spokane and Columbia rivers. Only well down the northern steep slopes is there any morainic topography. Even if it could be traced out as a record

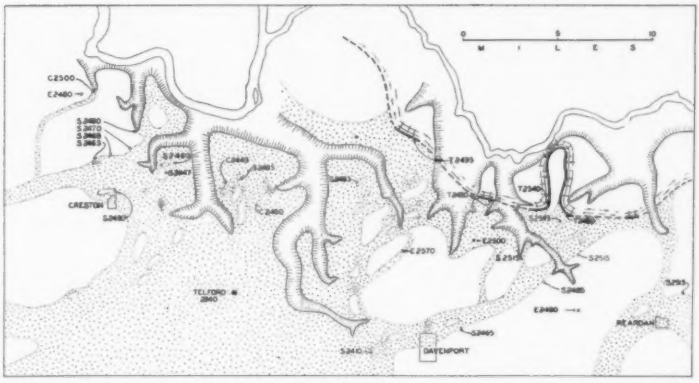

FIG. 7.—Head of the Telford–Crab Creek tract of channeled scabland. Most of the stippled area is well-marked scabland. Outlines of north-draining canyons indicated by hachures. Blank areas south of the river and the ice margins are largely loess covered. Figures are altitudes. T = Till; C = Channel floor; S = Scarp base; E = Erratic.

of ice margins, it is too far north of the channel heads and too low to bear on the question of shifting occupation.

Restudy has shown another thing regarding the glaciated tract north of Davenport. It is that the ice sheet did not reach as far south as formerly indicated. What had been taken in earlier reconnaissance for ice-laid till proves to be berg-laid. The divides between the north-draining canyons, previously unvisited, were found to carry *scarped relict hills of loess*, many of them 50 feet high, some 75 feet high, *separated by channels*, some with scabland floors. The channelways across these divides are roughly transverse to the divides and canyons. The altitudes of scarp bases, checked as care-

fully as possible in the absence of a topographic map, are with few exceptions higher farther north. Some channelways, when traced southward and southwestward, lead to northerly walls of canyons on which lie deposits of coarse angular basaltic rubble obviously swept out of the channels.

The combination of features here is remarkable. The loessial hills have not been glaciated. In their forms, relations to each other and to scabland, they appear to be identical with the relict hills of the scabland farther south. Floated erratics have been found among them, but not above 2,525–2,560. The associated scabland is not related to the north-draining canyons; it occurs only on the divide tops. Southward flow seems clearly indicated. The only conclusion which seems allowable is that the Spokane ice here did not reach the channel heads as formerly mapped, and that there was a broad sheet of water flowing vigorously southward across this scabland to become concentrated in the channel heads.

The revised map shows, therefore, only four separate spillway tracts from the ice. There may have been but three, though possibly there were five, separated by higher hills, against the northern slopes of which the ice sheet impinged. Since one of these (Moses Coulee) does not reach northward across the plateau divide, the number to be manipulated with shifting positions of the edge of the ice is reduced to two or three, possibly four.

Another feature of great significance in this proposed alternative of sequential instead of simultaneous occupation is the correspondence in altitudes of the northernmost channel floors, scabland-scarp contacts, and highest erratics floated back among the loessial hills. About forty such observations are available, fairly well distributed in significant places along 90 miles of the northern edge of the plateau. Almost every township here possesses all of these features. The channel floors are the lowest, but are nowhere known below 2,450. The floated erratics are the highest, but are nowhere known above 2,560. Much of this vertical range exists in virtually every township. The upper limits are essentially the same at either extreme of this 90-mile stretch.

Whatever may be the full significance of this remarkable uniformity, one conclusion clearly demanded is that irregular advance

and retreat of the edge of the ice sheet could have made very little difference in operation of the different spillways. They must have operated very largely together.

One possible sequence may be pointed out. The retreat of a cascade or cataract to form upper Grand Coulee, elsewhere set forth, eventually produced a canyon through the plateau divide. Scabland above the brink at the head of the canyon, recording early discharge, is about 2,500 feet A.T., nearly 1,000 feet above the canyon floor. If the great eastern spillways had an open-water connection, along the edge of the ice, with the Grand Coulee discharge at the time this retreating cataract reached the walls of Columbia Valley, or later, they would inevitably have gone dry. By far the largest part of the 2,800 square miles of scabland of the plateau lies in these eastern spillways. Much of the episode therefore saw the whole plexus in operation.

DIVERGENCES IN THE ANASTOMOSIS

There are about thirty major divide crossings and hundreds of minor ones in the scabland pattern. They are the heads of divergent routes. Several of the more marked divergences have already been described. Othello Channels is an example, the three Quincy Basin cataracts are examples, as are Devils and Palouse canyons. The latter two are especially significant since there can be no question of the existence and preglacial depth of the capacious valley from which they diverge, nor can post-glacial folding be called upon to explain them. The basalt of the Snake-Palouse divide shows only very slight warping. This doubtless determined the location of the original divide. But both the Snake and the abandoned Palouse valleys are almost wholly erosional in origin.

Changing location of ice edge surely never could produce any sequence in operation among the divergences of any one main route. It seems impossible that critics have intended to imply this, and improbable that they have carefully considered these numerous remarkable features. Granting, then, that divergences were due to overflow of divides, and knowing that there are only three definite source routes from the ice, all at essentially the same altitude, it follows that the divergences can be explained only by the simultane-

ous operation of glacial streams of the magnitude which the writer has repeatedly described.

CONVERGENCES IN THE ANASTOMOSIS

As previously noted, almost every confluence of glacial rivers was determined by a confluence in the preglacial drainage pattern. There are as many of these as there are divergences, and the entire plateau scabland system is converged to one canyon about 120 miles in direct line from the ice edge. If there was sequence in operation, then converging strands from two different source routes might be expected to record the fact. If the upper limits in the two channels just above the convergence have the same altitudes, this can be so only by coincidence. Gravel deposits made by the stream last in operation should block the mouth of the earlier route.

There are three places best suited to have this record. One is the convergence of Crab Creek and Grand Coulee drainage near Adrian; another is the convergence of Washtucna Coulee and the eastern part of Othello Channels near Connell; and the third is the convergence of Snake River, Esquatzel Coulee, and Columbia River near Pasco. All these are especially significant because Grand Coulee drainage is involved in each. It was shown in a preceding paragraph that the only probable sequence among the source routes was a capture of the whole discharge by Grand Coulee at the time its deep notch was completed. The reader will recall, however, that even this sequence required contemporaneous operation of the whole system for most of the scabland-making episode.

If we follow up this idea, Othello Channels spillover might well have been delayed until the capture turned all the glacial waters through Grand Coulee. It would thus clearly post-date the Washtucna Coulee River, which, by this scheme, would then go dry. So also would Devils Canyon and Palouse Canyon, and therefore the glacial river in Snake Valley. Thus the threefold junction near Pasco should likewise record this change.

But no suggestion has been found in the field that any such shift in operation occurred. Othello Channels eastern route, if brimful when the maximum depth of channel was attained, carried about 175 feet of water, 4 or 5 miles above the junction with Washtucna.

Washtucna Coulee, if brimful (and Devils Canyon proves that it was) carried a river 375 feet deep about 6 miles above the junction. Yet the upper limits of both glacial rivers at these places are very close to 1,100 feet A.T. Washtucna Coulee does have a large gravel deposit on its floor for a few miles above the junction, but this was deposited by its own glacial stream, as its form clearly shows.

The same evidence or lack of evidence is to be found in the other two places. The record at the Crab Creek–Grand Coulee junction is complicated by another item, the Wisconsin discharge through the coulee. But a wide spill out of Crab Creek crossed the angle between that valley and Quincy Basin, entering the latter about 10 miles from the channel cut by the Wisconsin Grand Coulee. At this place the record is simple and clear. The convergences, like the divergences and the heads of scabland channels, record contemporaneity, not sequence, of operation.

COLUMBIA VALLEY BEYOND THE PLATEAU SCABLAND

Despite the evidence submitted thus far, one may have a feeling that since the plateau is so little dissected, since so many drainage lines are hardly more than through the weaker sediments above the basalt, since there is a notable dip slope everywhere, and since there have been at least three glaciations of the northern edge of the plateau, a few mistaken observations and a few misinterpretations might be responsible for the Spokane flood blunder. Perhaps there is still hope for a conventional interpretation. Dr. W. C. Alden says: "It appears that ice sheets of three distinct stages of glaciation invaded the borders of the region and may have afforded conditions of repeated floodings of much smaller volume. . . . . The problem would be easier if less water was required and if longer time and repeated floods could be allotted to do the work." Dr. James Gilluly thinks it "exceedingly probable that . . . . a reinterpretation (of channeled scabland) is apt to be considerably more complex than the suggested flood hypothesis. . . . . That the actual floods involved at any given time were of the order of magnitude of the present Columbia, or at most a few times as large, seems by no means excluded by any evidence as yet presented." Dr. G. R. Mansfield says: "The general nature of the phenomena suggest conditions sim-

ilar to those attending the ice front in New York State, where temporary channels and falls now abandoned were developed. Although these were temporary, geologically speaking, some of them appear to have persisted for long periods of years. The scablands seem to me better explained as the effects of persistent ponding and overflow of marginal glacial waters, which changed their position or their places of outlet from time to time through a somewhat protracted period."

If there was one tremendous flood, if all labyrinthine canyoned tracts were brimful throughout their history, if violated divides were as high above preglacial floors as now, if the great gravel piles are simply huge river bars, if the loessial scarps are really river bluffs, if the profiles constructed from their altitudes are surface gradients of gigantic rivers, if the entire system actually does record what the writer has read from it, then Columbia Valley beyond the plateau scabland surely must bear witness to the event. It should speak authoritatively. Repeated floodings a few times as large as those of the present river might leave cumulative deposits, but not in great heaps with thicknesses equaling the sum of flood depths. Nor could floodings like those which made the Finger Lakes, Mohawk Valley, and Adirondack channels spill out of the deep Columbia Valley across divides into the lower course of tributaries, making scabland channels across these divides 600–750 feet above the river and building bars 400 feet high.

Though the writer has described features of this valley, pointing to an enormous river in it, criticism has ignored all but one of these. New data in two papers now submitted for publication, and therefore not presented here, will make the case for an enormous flood in Columbia Valley very difficult to explain away. The one feature which has received attention from critics is Wallula Gateway.

This narrow canyon of the Columbia, beginning 12 miles south of the entrance of the Snake and about 15 miles in length, is eroded across an unsymmetrical anticline, the continuation of the Horse Heaven Hills uplift. Typical scabland extends higher above the canyon floor at this place than anywhere else in the entire region. It spreads out above the canyon walls on both sides of the river. But since the upper slopes were not definitely cliffed and since the

loess mantle is thin, a transitional zone must be used in most places here for the upper limit. However, two fairly definite markers are available, one on each side of the river. Each of these requires a revision of previously published descriptions.

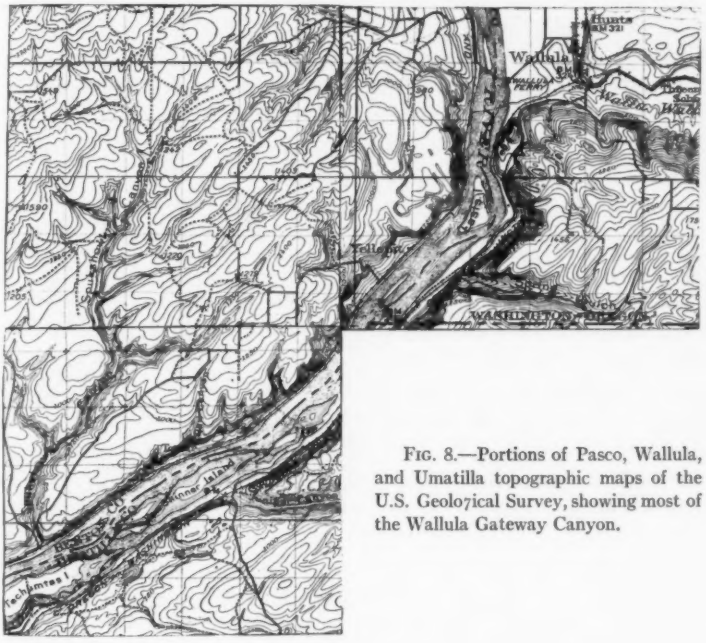

FIG. 8.—Portions of Pasco, Wallula, and Umatilla topographic maps of the U.S. Geological Survey, showing most of the Wallula Gateway Canyon.

On the west side of the Gateway Canyon (Fig. 8), a flat-topped hill nearly a mile long and elongated parallel with the canyon lies about a mile and a half west of the river. It is separated from the higher land farther west by a channel which at the head, the northern end, is more than 1,100 feet A.T. The hilltop is about 50 feet higher. This channel descends southward 150 feet in three-quarters of a mile over scabby ledges and has scabby sides farther south. At the channel head the old water course is not very well defined. Its floor has large low mounds and broad shallow depressions. There are no ledges here. Southward, where deeper, a clearly marked bar

fills the entire channel. The channel floor above it is a basin 25 feet deep (now drained by a small gully through the bar). On the south side the general channel floor is 45 feet lower. Channel walls are well marked here also. The southern part of the channel has been made by modification and enlargement of an earlier minor drainage line developed by local run-off. One affluent of the preglacial valley now hangs above the bar. The channel is too deep and far too wide to belong to the preglacial pattern. Apparently the flat-topped hill was not overrun, and 1,150± may be taken as the upper limit.

There is another and more marked channel parallel with the river and above the canyon walls on the west side. It is lower and nearer the river. It also leads southward. The two join half a mile from the top of the steep slope down which their present drainage spills to the Columbia. On this slope is a great mantle of coarse débris descending 300 to 400 feet from the upper scabland to the Gateway Canyon floor. This might be considered a talus slope or a steep fan which has climbed to the top of the cliffs. But its débris has come from erosion in the two channels, which are scabland features, not normal affairs. And nowhere else have talus or fan deposits in Columbia Valley closely approached the top of canyon walls. Genetically, it is a delta which is all frontal slope.

On the east side of the Gateway are more instructive features. Definite scabland extends up to 1,100, and scabby ledges in the northern part up to 1,150 and 1,175. On the northern slope of the upland (sections 34 and 35, T. 7 N., R. 31 E.) is a shelf or shoulder at 1,150+, with the 1,200-foot contour ringing a small portion out toward the lower slopes. This whole shoulder has been stripped of its soil and now bears only broken basaltic rubble and thin windrift soil in places. On the south and overlooking this rude bench is a definite scarp in loess 20–30 feet high, its base about 1,150 feet A.T. Above this no basalt is exposed anywhere on the upfold. All is covered with the coarse-textured loess. The waters which made scabland on the slopes of Wallula Gateway reached 1,150, probably 1,200, here. A more pronounced spur of the upland, in the eastern part of Sec. 35, a little over 1,100 feet A.T., is all scabland on its summit.

Thus both sides of Wallula Gateway have a trustworthy record

of water flowing through the canyon up to present altitude of 1,150, a hundred feet higher than previously reported. What was the depth of the canyon when this occurred?

Earlier interpretation called for considerable widening and deepening of Wallula Gateway by the flood. It was suggested that perhaps 200 feet of deepening had been produced. A part of the evidence of this was the existence of about 200 feet of "hang" at the mouth of Spring Gulch, a preglacial tributary entering the Gateway Canyon from the east. The hanging condition exists, but, like so many features of the scablands, simple map inspection is an unsafe route by which to reach an interpretation.

Spring Gulch heads in the loess-covered slopes of the basalt anticline and shows no bedrock above 1,550. It is a narrow, crooked, steep-walled but uncliffed gulch down to 1,000 feet A.T., where a level flat several hundred feet wide exists, underlain by about 25 feet of rudely stratified rubble gravel. Farther west this flat surface of the deposit grades into a sloping surface descending with the canyon and trenched by a deep gully. The basalt fragments of the fill are very little worn. They are not a contribution from the headwaters of the gulch. Several fragments of granite, one of them a foot in diameter, were found in the fill. Some basalt fragments appear perfectly fresh; others are rotten. Much silt occurs in interstices and there are some sand lenses.

The sloping surface terminates at about 700 feet A.T., there breaking off steeply, partially over cliffs in the débris, down to 550 feet A.T. The rest of the descent is over talus, slope wash, and rock ledges. At the bottom of this descent the preglacial slopes of the original gulch converge not far above present Columbia flood-plain level. The hanging condition therefore is due to a fill of rubble in the last mile of the gulch's length. This fill was introduced from the Columbia Valley, probably not so much by transit back up the gulch (though there are some foresets dipping away from the Columbia) as by lateral introduction over the northern spur between master and tributary valleys. The flat at 1,000 might record an approximation to the upper limit here, but probably is too low. The mingled fresh and decayed basaltic débris is what should be yielded if a great flood rose to sweep across long-exposed higher valley slopes.

The angular granite and diorite porphyry tell of berg-rafting across the scablands to this place. Wallula Gateway was as deep, or nearly as deep, before the Spokane Flood as it is today. And since undercutting at the mouth of Spring Gulch, as well as downcutting, would leave it hanging, apparently there has been no notable widening of Wallula Gateway at the bottom.

Another gulch on the southeastern side of the Columbia, near Juniper switch track, a few miles downstream from Spring Gulch, possesses much the same record. It is in the unmapped area of Figure 8. It is a smaller gulch, and the steep front of its rubble and gravel fill rises to 850 feet A.T., about 550 feet above the Columbia. This steep slope is almost as far out as the truncated spurs on either side. The surface gradient of the fill is much less than that of the gulch floor, much less than the surface slope of Spring Gulch fill. It ends abruptly upstream against steep slopes of basalt. Here it is composed of almost nothing but coarse, rudely stratified, angular fragments of Columbia basalt, though at the steep front there is a considerable proportion of well-rolled pebbles of foreign rock.

Juniper Canyon is the next tributary gulch down the Columbia, and nearly at the end of the Gateway Canyon. The spur between the two, 800 feet above the Columbia, is all scabland to 1,100 at least. Here are rock basins, buttes (two of them 50 feet high), jagged bare rock surfaces, a subsidiary small gorge right along the crest of the narrow spur, and two or three transverse gashes across from the Columbia to Juniper. Bars of gravel, flung out of the Columbia, occur on the summit in one place. The gravel which covers most of the northern wall of Juniper Canyon at its mouth has foresets dipping toward the Columbia, yet containing foreign material that could only have come across the spur *out* of the Columbia at altitudes of 900–1,100. There is no good scarp in loess here, but on the south side of Juniper is one about a hundred feet high, its base at 1,000. The deep deposit of flood gravel in the mouth of Juniper Canyon, now trenched, shows that the Columbia Valley here was essentially at its present depth when the flood occurred.

This will suffice to show the nature of the new data. They are essentially like all evidences previously published or included in this paper. But they indicate a considerably deeper "tremendous flood"; 300 feet deeper in the Gateway, to be precise. This will make ac-

ceptance of the Spokane Flood hypothesis more difficult than ever. One may find, with Dr. Gilluly, that higher talus ratios in the upper part of the Wallula scabland mean pre-Spokane age, not a more readily weathered phase of the basalt, not the absence of vertical cliffs. Gilluly surely could not tolerate a pre-Spokane flood, therefore the Gateway itself was very much short of its present depths when the highest scabland was formed. But this conception is barred here, everywhere in the scablands, and down the Columbia by the consistent testimony of the valley system. It predates all scabland. Scabland surfaces, cliffs, rock basins, loess scarps—all would long since have vanished as such if they were of such physiographic antiquity. They are among the most youthful erosional features of the region. They are superimposed on the preglacial valleys and divides.

An important fact regarding Wallula Gateway is that its highest scabland levels are 100 feet, perhaps 150 feet, higher than upper limits in the Snake, 20 miles distant upstream. Since a broad structural valley lies between the end of Snake Canyon and the head of Wallula, conceivably a ponded tract here might carry the flood profile across without a drop in the surface. But the fact that it is higher seems to have but one explanation. It is that post-flood uplift of 100–150 feet has occurred along the axis of the Horse Heaven Hills anticline. Such evidence, if it existed in the proper places, would help to dispense with the flood hypothesis for the divide crossings. Wallula Gateway, however, does not belong to that category. This strong suggestion of recent uplift notably weakens the estimates on the volume of the flood, published earlier by the writer. If the record of surface gradient has been diastrophically disturbed, one essential factor for the computation is lacking.

One last point regarding Wallula Gateway. With a depth and a bottom width but little modified by the flood, the idea of "bottleneck" ponding at the Gateway ceases to have validity. Dr. Alden remarks that "it seems as though the estimated capacity of Wallula Gateway, when fully opened, is too great for this gorge to have served as a bottle-neck to hold above it a flood of such dimension to the level called for in the explanation offered." If, then, it was essentially fully opened all the while,[1] what becomes of the idea of

[1] Exception being taken for a large lateral canyon east of the river, and for considerable erosion on the slopes here.

the ponding? Again we must appeal to the Columbia Valley testimony. As will be shown in a paper on the great bars down this valley, the tremendous river was in every place, except one, much higher than earlier accounts would indicate. For that one, at White Salmon, Washington, a local uplift was suggested. But the White Salmon bar now falls into the new and higher profile recorded by many previously undiscovered bars and divergent channels. The ponding was caused by the immense volume of flowing water in the valley below Wallula Gateway.

PONDING IN NON-SCABLAND VALLEYS

There is one remaining test for simultaneous occupation of all channels. When one canvasses the problem deductively, he realizes that if the great flood ever occurred, and if the present Columbia Valley system then existed, there should have been noteworthy ponding in the lower part of Snake River Valley (above Palouse Canyon), Walla Walla Valley, Yakima Valley, Umatilla Valley, John Day Valley, Des Chutes Canyon, and all other tributaries entering from non-scabland regions. The presence of pond deposits definitely related to the scabland rivers should establish the flood beyond any further reasonable doubt. Absence of such deposits should renew the effort to find workable alternatives for the scabland phenomena themselves. The rub, however, is to show that pond records, if they do exist, are definitely related to the scabland rivers. Glacial waters backed up the tributary valleys there undoubtedly were. The striated erratics prove that. But the critical reader recalls that a late Pleistocene submergence, probably Wisconsin in age, has been described for the region. This submergence is generally accepted as due to a lowered level of this part of the continent. It was like the Champlain submergence of the St. Lawrence Valley. How can one know that foreign material back in these valleys does, or does not, belong to this submergence?

And though erratic boulders and cobbles logically should be a part of the record of the assumed Spokane ponding, they should constitute only a small part of that record. Where is the immense quantity of loess that was swept off the scablands? Should it not be very much in evidence as a stratified silt in the supposedly ponded valleys?

This pertinent challenge was introduced in the discussion which has been referred to repeatedly, but it did not appear in the printed account. The writer has been unable to learn who proposed it. At that time this challenge could not be answered with observational data, for these valleys had not yet been critically studied. Nor is there yet enough known in detail to furnish an adequate basis for any connected story of events in the ponding of such non-scabland valleys. But enough is known to show that some extraordinary episode of sedimentation has occurred in them. Data from Walla Walla Valley may be generalized as follows.

A widespread deposit mantles the Palouse loess or completely buries it throughout the entire Walla Walla Valley below 1,050 to 1,080 feet A.T. It extends back up the tributaries to similar altitudes. Almost all recent road cuts below 1,100 show it. But no such cuts above that altitude show it. Instead, they show only reddened loess with calcareous cementation in nodules and seams and a cover of unconsolidated, apparently little weathered dust 2–4 feet thick. Here and there basalt appears beneath the loess.

The sedimentary deposit in question is stratified and is varied in character. The following differentiations in material have been observed. This list is not a section. No definite vertical sequence among the different constituents has been observed.

1. Coarse, angular, black (fresh) basaltic sand and gravel. The coarse black sand seems the most widely distributed, vertically and horizontally, of all the listed constituents. It commonly occurs in lenses and pockets and is very widely disseminated in grains throughout the silt layers.

2. Very fine-textured, light-colored sand. It is almost as fine as loess in many strata. In some fine gravelly phases of the deposit it occurs as very definite but very irregular lenses. It apparently is not a derivative from basalt rock. It may represent the coarser part of the Palouse loess.

3. Grayish to slightly brownish silt, comparable to Palouse loess in color and texture. To the touch, this silt is loess. Except in some gray phases it is Palouse loess in color also. But it occurs in strata, and some of these strata show laminae.

4. Pebbles and cobbles (a few boulders) of holocrystallines,

metamorphics, and other foreign rocks. A very great variety represented. Some of these are rolled, some are bruised, facetted, and striated. Some are as angular as though directly from a rock crusher. They have been dropped from floating ice. They are not common in the gravelly and sandy phases of the deposit, but are almost always to be found in any cut where the silty phase is dominant.

5. A clayey and sandy matrix, yellowish in color, which surrounds groups of the foreign rock fragments. This phase is but rarely found and is strictly limited to these pockets of foreign angular and subangular gravel. The aggregates of matrix and larger fragments look like till. It seems very probable that they are patches of till, dropped from floating ice in masses a foot to three or four feet across, flattened into a stratiform lens because of a soft, muddy condition.

6. Various combinations and interminglings of the constituents before listed. The most common combination is a sprinkling of the coarse basaltic sand and small basaltic pebbles through the silt Another common combination is foreign pebbles scattered through the silt.

There is a definite directional variation in the composition of the deposit. In the west-central part of the valley it is mostly sand and fine gravel. Near the northern, eastern, and southern margins, closer to the upper limits, it is mostly silt and very fine sand. This horizontal distribution is to be correlated with distance from Columbia Valley. With this is a range in thickness also, the thickest portions known (150 feet maximum) being farthest west. The disseminated large basalt sand grains are less abundant near the eastern and upper limits, though foreign pebbles seem to be as common here as elsewhere.

Cross-bedding is common in the coarse sand and fine gravel. Near the mouth of the valley, foresets in fine gravel dip eastward, up the valley away from the Columbia. Cross-bedding in the finer constituents is rare. Sequences in stratification do not seem to indicate any clearing of sandy, muddy water, such as seasonal variations in glacial melting might give. All that can be said yet is that thickness and order of the strata of different materials seems variable and unsystematic. Marked irregularities in stratification of

sandy phases occur. One such structure is illustrated in Figure 9. No satisfactory explanation for this is at hand.

There is virtually no weathering or cementation in any phase of the deposit. There is no brownish, yellowish, or reddish stain to the upper part. Some granitoid pebbles crumble readily, but associated with them are apparently perfectly fresh pebbles of much the same kind of rock. In some of the basalt sand and fine gravel there are distinct strata of the colored alteration products of decomposed basalt alternating with similar strata of fresh black basaltic sand and gravel. It is obvious that this decay did not occur after deposition.

FIG. 9.—Contorted bedding in silt and fine sand, Walla Walla Valley. Etched into relief by the wind.

Whatever conditions were responsible for erosion of the débris, for transportation to the Walla Walla Valley, and for the peculiarities of its deposition here, they surely involved the destruction of a great deal of well-weathered basalt. In some sections a slightly calcareous zone lies a few feet below the surface, but lime is markedly less in amount than in the Palouse loess at similar depths.

The topography of the deposit is exceedingly interesting and rather surprising. All the numerous creeks of the Walla Walla plain have cut 50 feet or more into it and have widened their valleys to the proportions of flood plains. Divides between creeks, where composed of the finer material, carry a multitude of minor drainage lines, only the tops of the divides recording the former plain of aggradation. The topography of the silt deposit in many places blends into

that of the higher mature hills of loess. The coarser phases, where dominant, are less dissected and have broad aggradational slopes, descending southward, away from the open Walla Walla Valley and the nearby Columbia, almost as definite as the aggradational slopes of the bars of scabland. If the deposit is of the same age throughout the valley, the differences in amount of erosion apparently must be ascribed to differences in porosity.

The preceding generalized description for the Walla Walla Valley is equally applicable to Snake River Valley and its tributaries above Palouse Canyon. There is nothing to add, and almost nothing to subtract. The curiously contorted bedding in sand has not been found. And apparently the steeper slopes in general determined sloping, instead of flattish, surfaces in the deposit. There is one significant change to make, however. The upper limit is 1,300–1,350, not 1,050–1,080. A separate pond is recorded, its surface about 250 feet higher, though only 12 miles distant at the narrowest place in the divide. By valley route it is 40 miles distant.

The fact that the scabland upper limits at the mouth of the Snake River pond is 1,325 and at the mouth of the Walla Walla pond is 1,050–1,100 may be only coincidence. The reported difference in altitude may be an error. The abundant unweathered basalt grains scattered through the silt may have no genetic connection with scabland erosion. The floating ice recorded by the glaciated erratics in scabland channels may not have drifted back up these ponded valleys during the scabland epoch. There was probably a later glacial episode, with widespread berg-drifting. The apparent record of abundant decomposed débris associated with perfectly fresh basalt may be a mistaken interpretation. The unusual and widespread mingling of coarse basaltic sand grains through silt and fine non-basaltic sand may have some simple explanation. In short, the writer's study of these pond deposits may be too limited as yet to afford a connected story of events here. But the probability of backwater pondings by the Spokane Flood is obvious.

TESTS OF THE SPOKANE FLOOD HYPOTHESIS

The unique scabland features and unique combinations of these features should afford in their relationships a particularly valuable

clue to their origin. One may think of a single scabland canyon in terms of a relatively small river working for a long time, but he is sharply checked in applying this idea by the high-level divergences, the huge channel basins, the great bars, the loessial scarps back from the edge, etc. These features are not possessed by canyons with orderly and long-continued histories. So throughout the whole category. The conception of a flood explains these features and their simpler combinations, hence is justified at least as a hypothesis. But will it explain all the relationships? If essentially correct and complete, it must. If it fails, then either fundamental error is indicated or complications of the relatively simple story are involved.

THE QUINCY BASIN CATARACTS

A test for the hypothesis is available in the relations of Crater, Frenchman Springs, and Potholes cataracts to the flood in Columbia Valley. Their upper limits are about 1,300 feet A.T., their cliffs 200–400 feet high (including plunge pools), the bottoms being 100–300 feet below the upper limit of the flood in this part of Columbia Valley. It appears that some sequence here is necessary. The writer previously used the conception of bottle-neck ponding at Wallula Gateway; enlargement of this canyon lowering the flood in Columbia Valley while the scabland rivers were still operating. But this now seems completely barred out, and what sequence did occur is not apparent. If the situation cannot be explained with good supporting field evidence, the hypothesis becomes suspect.

FLOODING IN COLUMBIA VALLEY ABOVE MOSES COULEE

Nothing has been said in the writer's publications about the flood in Columbia Valley above the mouth of Moses Coulee. That part of the valley has not yet been studied. If the hypothesis is correct, a record of the flood must exist here, either of great flow from the ice, or, less probably, of a backwater pond. In the first case we expect the huge mounded bars, the recently scarred cliffs high above the river, the buttes and basins back on high rock terraces, the scarps in overlying weaker formations if contact occurs at the right altitudes. We expect that such scarps will be distributed northward along a rising profile, starting at 1,300 feet A.T. at Crater Cataract.

In the second case there should be widely distributed fine sediments up to a horizontal plane of about 1,300. If neither of these exist, the hypothesis is fundamentally wrong.

The west side of Columbia Valley, opposite Quincy Basin, must carry a record of the flood if the hypothesis is to survive. The record here apparently must be one of flowing water, though if only Moses Coulee and the three cataracts contributed, that flow might not be especially vigorous. Upper limit data here should be directly related to the history of the cataracts.

COLUMBIA VALLEY BELOW WALLULA GATEWAY

This valley has been studied largely on the Oregon side. If the flood hypothesis is in error, the so-called upper-limit features should somewhere, presumably on the Washington side, be so far out of proper position that another explanation would have to be constructed. These features, if not due to a flood, should be absent at the altitude required; they should be found too high or too low, or in non-scabland valleys. Two or more sets of them on the same slope might exist if local conditions alone were responsible. If the many so-called bars and the several so-called divergences of the Oregon side have been incorrectly interpreted because, let us say, of absence of features which would reveal their real origin, search of the Washington side should be expected to uncover them. Trustworthy criteria of their true genesis should not be lacking everywhere. If the hypothesis is correct, the constructional bars should exist in Washington as well as in Oregon, with the proper relations to scabland upper limits, to divergences, and to mouths of tributary valleys.

Several significant places for such study may be pointed out. Sillusi Butte, north of Plymouth, should have the scarp-scabland-gravel combination not much below 1,100 feet A.T. The mouth of Rock Creek should carry large remnants of a tributary mouth bar, thrown back into it from the Columbia, its height not exceeding about 600 feet above the river. Other tributary valleys should have the same record, though at different altitude limits, depending on location along the Columbia. The south face of Columbia Mountain should carry the scabland-scarp-gravel combination at about 900 feet A.T. The north side of the structural valley at The Dalles

should have it at about 750. This list might be multiplied indefinitely. One cannot be sure that the record will be present, but if it is, the hypothesis should be credited with having led to new field evidence, and therefore should be correspondingly strengthened. Altitude data are not yet ample enough to justify assertion or denial of post-flood warping along this stretch. This item may develop with later study.

DO THE SCABLAND PHENOMENA RECORD SEVERAL DIFFERENT EPISODES?

The suggestion has been offered by several that the record of the supposed Spokane Flood is really a much more complicated affair, that it is a product of several episodes of glacial spill, the records of which have been uncritically grouped together. This has been put into concrete form for one place in the scablands, the vicinity of Dry Falls and Hartline Basin, Grand Coulee. Presented in this fashion, it exemplifies the type of criticism by which the flood hypothesis will become established or eliminated. It is built on detailed facts instead of general opinions.

Hartline Basin (Fig. 10) carries a considerable gravel and sand fill above the coulee floor. The flattish surface of the gravel plain breaks off to the west in a steep descent to the scabland above the falls. On this western slope are two terraces. The lowest stands 1,650 feet A.T., about 100 feet above the coulee floor, and is composed of silt, possibly Nespelem (Wisconsin in age). The next terrace is 1,750 feet A.T. and is composed of gravel and sand. Bones of a camel from a well in this terrace have been reported by Dr. Kirk Bryan. Dr. O. P. Hay thinks they belong to *Camelus* or *Camelops*, and that this terrace deposit therefore is probably first interglacial in age.[1] One hundred feet still higher is the surface of the Hartline gravel plain, covering about 25 square miles. Here apparently is a record of several stages in the development of Grand Coulee, one of which may be dated from the fossil bones. Which of these episodes was the Spokane Flood? In how many places in the scabland may this sequence be unrecorded or obscure, and whatever features exist have been corraled therefore for the flood hy-

[1] "The Pleistocene of the Western Region of North America and Its Vertebrated Fauna," *Carnegie Institution, Publication 322B* (1927), p. 257.

pothesis? The challenge certainly is justifiable. But before one concludes that this series of terraces affects the hypothesis, let us examine more evidence from Hartline Basin.

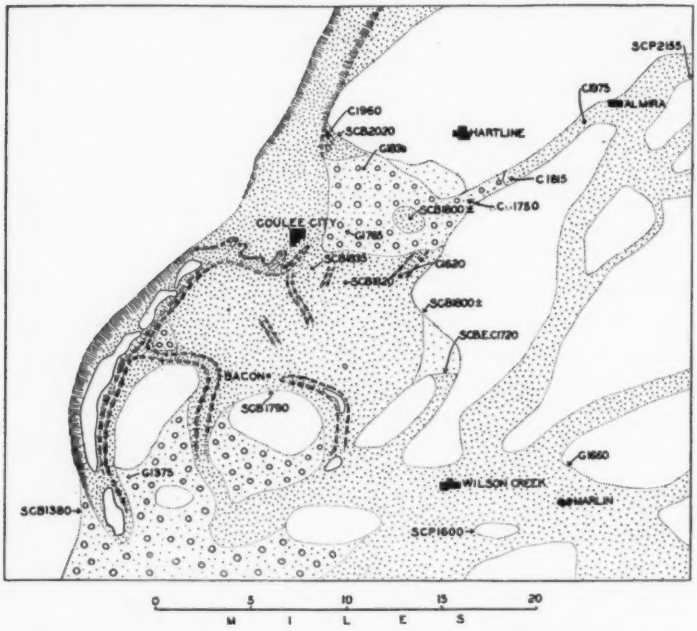

FIG. 10.—Sketch map of scabland features of lower Grand coulee and vicinity. The closely stippled areas are scabland; the tracts with stipples and circles are gravel covered; the widely spaced stipples indicate ponded tracts; the blank areas with dotted outlines are loess covered; and those with continuous outlines are lakes. Figures show altitudes. SCB = Highest scabland; SCP = Base of loess scarp; C = Channel floor; G = Upper limit of scabland gravel; E = Erratic boulders.

These terraces are all below the upper limits of scabland here! There are four places (shown in Fig. 10) which clearly record this fact:

1. The mouth of upper Grand Coulee, 4 miles north of Coulee City, has a prominent salient on the east side, jutting out about a mile between the coulee on the west and Hartline structural basin on the southeast. The 500-foot cliffs of the west side of this salient (the east wall of the mouth of the upper coulee) show the tilted

flows of the monocline only in the extreme southern part. The southeast slope toward the gravel-filled basin is not far from the dip slope. This salient is about 200 feet higher than the adjacent gravel fill, the uppermost terrace which Hay describes from Bryan's unpublished report. The top of the salient is all scabland! Across its summit, close to the higher, soil-covered slopes at the northeast, is a scabland channel 50 feet deep, 600 feet wide, and more than half a mile long. This channel leads with descending gradient *out* of Grand Coulee and *toward* Hartline Basin. Its head is a notch in the summit profile of the salient, 1,960 feet A.T., plainly seen from the highway on the gravel plain. A few hundred yards farther south on the summit of the salient lies another channel, about 30 feet deep but not notched completely across the spur. Its head is amphitheater-like, open to the southeast, and separated by a wall only 50 feet across at the head from the summit of the great cliff descending to the coulee floor 500 feet below on the west. The amphitheater records a subfluvial cataract whose plucking made the channel, but which was abandoned a little before the last of the basalt was torn out to complete a notch such as the northern channel possesses. The channeled scabland salient appears to be a record of the initial spill down the monocline from the north. It indicates that no adequate pre-scabland drainage route occupied the site of upper Grand Coulee. The oldest gravel terrace known in Hartline Basin is the flat. Its highest altitude is 1,835 feet A.T. (1,850, Bryan's figure), or 125 feet below the head of the channel notch on the salient. The highest scabland is as old as this fill. It has been modified by weathering and by deposition of dust and sand as little as any other scabland on the plateau, except that of Wisconsin age.

2. About four square miles of scabland exists out in the middle of Hartline Basin. Buttes and rock basins here with a relief of 40–50 feet stand above the aggraded plain and have mounded gravel accumulations with steep slope on the south or lee side 30 feet high. This scabland is not much less than 1,800 feet A.T. Its situation out in a broad aggraded tract, the continuation of the upper terrace, needs explanation. Running water is the explanation. To put a current of sufficient vigor across this broad flat tract requires very great volume.

3. A minor spillway of the anastomosis of the plateau, previously unmapped, diverges southwestward from the Wilson Creek channel near Almira, crossing the preglacial divide to enter the eastern end of Hartline Basin. The channel floor at the head, on the divide, is 1,975 feet A.T. Where it fades out into Hartline Basin fill its floor is about 1,750. The gradual loss of channel character in the gravel deposit at this altitude shows that it dates from the same episode that made the Grand Coulee upper scabland and the scabland and bars in the middle of the basin. All are above the terraces noted by Dr. Bryan. The initial Grand Coulee discharge was the flood discharge. It coincided with the Crab Creek flood discharge. The persistence of small rock basins on the floor of this narrow channel and of the definite loessial scarps bounding part of it seems difficult to harmonize with the early Pleistocene age suggested for the contemporaneous Hartline plain.

4. The southern rim of Hartline Basin is very significant in this problem. It is all scabland from Grand Coulee on the west almost to the mouth of this channel on the east, a distance of 7 or 8 miles. At least three distinct notches are cut into it (not counting Grand Coulee), the largest of which is Deadman's Draw, well toward the southeastern corner of the basin. The floor of this draw is 1,620, the top of its walls is 1,760, and the upper limit of scabland two miles to the southeast is 1,800±. Deadman's Draw is nearly a mile wide at the top of its walls, and in all likelihood it is a preglacial drainage line out of the eastern part of the basin. But the volume of water entering the basin, almost wholly from Grand Coulee and certainly predating the later episodes of the lower terraces, simply overwhelmed all of the southern rim. Altitudes of 1,820 and 1,835 are reached by the higher buttes of this pronounced scabland. From the unnotched portion of the southern rim the gravel floor descends northward and westward something like 15 feet to the mile. Yet this gravelly débris of Hartline Basin surely was not moved northward. Nor could it have come by way of the minor channel from the Crab Creek anastomosis. It came out of Grand Coulee in the earliest episode of glacial discharge which is recorded here. Its slope against the direction of current can be explained only by the conception of a great stream. It is river-bottom, not river-floodplain,

topography. This up-current descending slope is a consistent feature in scabland gravel deposits.

The writer does not believe that any noteworthy canyon had been developed along upper Grand Coulee at the time the Hartline scabland and gravel features were made. But he does insist that, even if there were no canyon at all, these features of the basin clearly indicate an initial episode of very great flooding, one that clearly antedates the lower terraces noted by Bryan and Hay. The extensive gravel fill of Hartline Basin was not made in backwater; it and the associated scabland tell of notable current across it from northwest to south and southeast. Four or five different stages may well be recorded in the terraces north of Coulee City. The earliest was the flood episode.

Hartline Basin may well have preflood sediments beneath the gravel, just as Quincy Basin appears to possess, and the camel bones may have come from them. That the camel became extinct everywhere in North America shortly after the first interglacial epoch is questioned.[1] For these reasons it seems doubtful that these bones may be used to date the terrace, and doubtful therefore that the youthful topography of scabland dates back to the first glaciation.

FLOODING IN STRUCTURAL VALLEYS

Since scabland high on the walls of erosional valleys might be a record of early stages in that valley's development, some may render judgment on the writer's interpretation as "not proved." But if a structural valley could be found, essentially unmodified by erosion or deposition before the glacial waters arrived, and so placed and proportioned that a relatively small glacial stream could pass through, it might afford significant evidence. Such a valley of adequate width and depth could not have high-level scabland by the alternative hypothesis. If it had high-level records at all, they would be only of ponded water.

Since such a valley is not impossible on the Columbia Plateau

[1] J C. Jones, "Geologic History of Lake Lahontan," in "Quaternary Climates," *Carnegie Institution, Publication No. 325* (1925), pp. 49–50. Kirk Bryan and J. W. Gidley, "Vertebrate Fossils and Their Enclosing Deposits from the Shore of Pleistocene Lake Cochise, Arizona," *American Journal of Science,* 5th series, Vol. II (1926), pp. 487–88. A. S. Romer, article to be published in *Science.*

in Washington, where structure is directly responsible for the major relief features, the writer kept this test in mind during the 1927 field season, hoping to find the combination required. And two valleys which appear to meet the conditions were found. Both are in Grant County, south of upper Crab Creek and east of the northern part of Quincy Basin. They are sub-parallel, oriented about northeast-southwest, lying across the downstream angle between the creek valley and the basin. The western of the two structural valleys is in open connection with the creek's erosional valley, the junction being south of Wilson Creek station. Chain Lakes, 2 or 3 miles from that station, lie in this broad structural sag, about 100 feet higher than the creek valley floor.

Though the slopes of the broad streamless valley are strikingly cliffed, there is no canyon form such as Crab Creek possesses. The cliffs are set back like great risers, and there is much channeling along the slopes. Rock basins, however, dominate in the part examined. They range from 30 to 50 feet in depth. They are so thickly set that, if topographically mapped, apparently as much area would come within hachured contours as outside of them. No dipping flows were seen. The deformation involves a sag of 200–300 feet in a tract about 5 miles wide. Crab Creek below the junction with this broad valley must have held its pre-deformation course during the warping. It cuts through land that is higher than this route.

The upper limit of scabland at the head of this divergence is 1,600 feet A.T., 275 feet above the floor of Crab Creek and about 175 feet above the floor of the sag. A wide sheet of water flowed out of Crab Creek Valley here toward Gloyd, on the eastern rim of Quincy Basin, its surface descending about 300 feet in 12 miles. Erosion was limited to etching out the cliffs and basins on the slopes of the sag.

The eastern structural valley is smaller and looks more like a stream valley. It has no open connection with Crab Creek Valley just to the north. On its floor is a string of rock-basin lakes 2 miles long, known as Long Lake or Black Rock Lake, in a setting of scabland cliffs that extend 250 feet up on the slopes. Water flows westward along the string of lakes.

A mile east of the lakes the valley is about 2 miles wide and has long gentle slopes without marked scabland, though also without a loess cover. Altitude of its floor here is about 1,550 feet A.T., 150 feet higher than Crab Creek floor at Marlin, almost directly north. The valley here is streamless and its floor is marked by broad sags and swells. This is near the head. Two miles farther east is well-marked scabland on the divide between Crab Creek and the structural valley. Upper limits on the divide are a little above 1,650 feet A.T. Glacial water indubitably flowed out of Crab Creek route across this divide and moved southwestward along this sag. Where wide enough, no scabland was produced. Where narrower, as at the lakes, erosion occurred on the slopes over a vertical range of 250 feet. No dipping flows were seen here, but the topographic relations seem to make a clear case for structural origin. The sag probably had free drainage southwestward before the episode of the flooding (for it contains no fill), but its divide at the north was more than 250 feet above the floor of Crab Creek Valley.

If these two valleys across from lower Crab Creek to northern Quincy Basin were open structural affairs when glacial diversion across the plateau first occurred, divergent streams from the glacial Crab Creek river were voluminous enough to leave the scabland record as high on their walls as on Crab Creek Valley itself. Repeated floodings of smaller volume would never do this, even if Crab Creek Valley was shallow at the beginning of the assumed series of floods.

POND OUTLETS

If the larger structural and erosional valleys of the plateau antedate glaciation, and if glacial waters ever were of the volume which the writer has set forth, then the ponding or backwater in the unexamined valleys should in some place or places have been high enough to escape through the lowest saddle in a margining divide and to enter an adjacent valley. This combination could not be expected to divert water from the Columbia system, but it might be expected to produce a local scabland channel, unconnected at its head with the rest of the system. This channel head should correspond in altitude with the highest record of ponding and with scarp bases of the particular scabland river responsible for the ponding.

Such a setting is provided by the pond of Snake Valley above Palouse Canyon (1,350 A.T.) and that of Walla Walla Valley (1,050–1,080 A.T.). But the separating divide everywhere appears to have been higher than the Snake Valley pond. Another place for this combination is Yakima Valley and Columbia Valley, with the separating Horse Heaven Hills. But here again the divide between is everywhere higher than the flood could have been in Yakima Valley. Another divide that might have been crossed by discharge from a ponded tract, had it been low enough, lies between Walla Walla Valley and Umatilla Valley. It is a continuation of Horse Heaven Hills anticline, and, had it been crossed either here or south of Yakima Valley, the crest of the flood through Wallula Gateway would have been lowered.

The most striking place for a possible realization of pond discharge lies in Idaho, in the large valley occupied in part by Coeur d'Alene Lake. Discharge should have been across its southern or western rim. This rim divides the lake basin from the headwaters of Potlatch River (flowing south to the Clearwater and thence to the Snake), Palouse River (flowing west to the scablands) and Latah Creek (flowing northwest to Spokane River). The rim is lowest on the west, there being only 2,750–2,800 feet A.T. But it nowhere shows a scabland channel across this divide to Latah or Palouse drainage, though there are many berg-drifted erratics ranging up to 2,550 all around the lake. The Spokane ice did not close the northern opening of the Coeur d'Alene Valley, and ponded water here escaped westward along the south side of the Spokane Valley to the eastern head of scabland, where scarps, erratics, and channeled basalt ranging from 2,450 to 2,550 are found.

This recital will suggest that there is little hope of finding a place to apply the proposed test. Very probably no major example exists. Two minor ones, however, have been found in the field study. One of these has been described in a paper on the bars of channeled scabland, now submitted for publication. The other will be described here. It is a small valley entering Crab Creek from the north, a few miles east of the mouth of Grand Coulee. Its scabland is limited to the bottom and lower slopes, and is not pronounced. But it has

gravel deposits of the type associated with true scabland and unknown in valleys of the plateau, which carried no glacial waters. It also has erratic pebbles, cobbles, and boulders. Traced northward, upstream, these features are found to the head and on the divide at the head. (SCB.E.C. 1,720 on Fig. 10). But down the opposite slope of this minor divide there is only the mature topography with its mantle of fine material. No scabland exists here.

An earlier statement by the writer, that every scabland channel when traced up-gradient leads continuously either to another scabland tract or to the glaciated area, is not true for this place. This scabland ends on a divide top, with only the normal surface to the north and west of it. Alternatives which clamor immediately for recognition are as follows: The scabland may be a product of local run-off, or it may be an exhumed rugose surface of the basalt. The gravel may be of local stream origin or it may have come to light with removal of the loess by the local stream. The erratics may have been floated back in the later submergence, or they too may have been buried beneath the loessial cover and only locally exposed.

We are not limited, however, to these features alone. The altitude of the divide where the highest scabland and erratics occur is known. And the existence of a large scabland tract to the north and west is known, a tract lower down the western slope of this divide. It is the broad area south of Hartline Basin, the highest isolated scabland buttes of which are 1,820 and 1,835 feet A.T. The glacial waters flowed southeastward across this scabland, escaping from the main Grand Coulee route. The upper limit on an island tract, 9 miles almost directly west of the divide we are considering, and therefore somewhat upstream, is 1,790. The divide at the head of the minor scabland route is 1,720. If flowing water in the larger tract were up to 1,790 on this hill, it must have caused flooding back on the gentle western slope of the divide. A pond record should exist over this slope which lay below the flood level but out of the main currents. There has been no opportunity yet to search for it. But if it does not exist, something is wrong with the flood hypothesis. If it does exist up to this divide and no higher, only the flood hypothesis will explain the entire combination of features here.

POND DEPOSITS

There are several valleys entering scabland which have not been studied except at their mouths. If they fail to carry the pond deposits at appropriate altitudes, something is wrong in the scheme. Also, if the ponding was due to ordinary seasonal melting, varved clays and silts should record the fact. If pulsatory elements of any kind were involved, the fact should come to light from a study of the backwater deposits. It seems likely that these records of standing water will contribute more toward an understanding of the nature of glacial discharge across the plateau and down the Columbia than will the records of running water. They constitute a sedimentary record, a cumulative record. Except for the bars, all else is essentially a surface of unconformity without an overlying deposit.

FOSSILS IN FLOOD SEDIMENTS

If the writer's hypothesis be correct, the various sediments ascribed to the Spokane Flood should be unfossiliferous. To date, no fossils are known from them. Dr. Hay's lists of Pleistocene vertebrates from Washington and Oregon[1] contain no finds which, in the writer's opinion, clearly come from scabland deposits. Some discoveries are reported from scabland tracts at altitudes below the local upper limits, but burials were in other sediments in those tracts. If fossils ever are found in the so-called flood sediments, and if they were not derived from destruction of older deposits, and do not come from older deposits beneath or younger deposits above, a quite different interpretation must be devised for the scabland sediments.

CONCLUSION

The cause of the Spokane Flood is unknown. The cause of the glaciation which was an antecedent of the flood is also unknown. Many suggestions for the cause of Pleistocene glaciation have been discarded as inadequate or impossible. It is far from safe, however, to conclude that the incompetence of any particular postulated mechanism to furnish the ice sheet required by our interpretation of the field evidence seems to call for a reinterpretation of that evidence. It would be much safer first to show that the field evidences

[1] *Carnegie Institution Publication 322B.*

are inconsistent with themselves when glaciation is read from them, and that they have some more satisfactory explanation. The writer hopes earnestly that this method of approach to the problem of channeled scabland will not be neglected. Only through adequate familiarity with its features can it be judged. Only thus can workable alternative hypotheses be constructed. If and when these appear, the writer's explanation may be discarded, having to its credit only that it provoked adequate study of a most extraordinary assemblage of unique physiographic forms.

A SILICEOUS SHALE FORMATION FROM SOUTHERN CALIFORNIA

R. D. REED
Alhambra, California

ABSTRACT

In this paper the attempt is made to describe a particular section of organic siliceous shale in as nearly objective fashion as possible, and to interpret the facts without reference to any hypothesis about the origin of the "Monterey shale" formations. The samples selected for study turn out to be very different from "typical diatomaceous shale," and to contain a varied and interesting assemblage of detrital and secondary minerals, and especially of micro-organisms. Its constituents suggest that the material may have accumulated in a fairly open sea, not many miles from land, in water from a few hundred feet to a few hundred fathoms deep. However different these rocks may be from more "typical" organic shales, there is some evidence that they may have been concerned in the genesis of southern California oil.

The method commonly adopted for the solution of the Monterey shale problem is to deduce consequences for the formation as a whole, and for all the allied formations containing siliceous organic shale, from the study of a few outcrops or samples selected as "typical." Though clear-cut and simple, and yielding definite results with a minimum of time and effort, this method has nevertheless two fundamental weaknesses. In the first place, the idea of a "typical" specimen involves the assumption that these formations are fairly simple and uniform in lithology, whereas in fact the exact reverse is the case. Instead of being composed dominantly of material clearly diatomaceous in origin, most of them have good diatomite as a rare though striking and interesting constituent; and demonstrable diatomaceous material of any kind may be absent from sections thousands of feet thick. The formations may include thick breccias with blocks as big as a house, and others with most constituents so small as to escape ordinary observation; a coarse conglomerate may change laterally within a few hundred feet into good siliceous shale; some sections are composed largely of thin-bedded sand and silt beds, or silt and diatomite, or silt and sponge

remains; some contain material that looks typically diatomaceous, but actually has other siliceous organisms present in greater abundance than diatoms; some have much volcanic glass, while others have little or none; a few sections are composed largely of a peculiar secondary limestone, and in others, normal limestone with numerous fragments of calcareous organisms is an important constituent; some have abundant hard opal and chalcedony, either in thin persistent beds or in discontinuous streaks and lenses; others have no such material at all. Instead of being simple and comparatively homogeneous, the siliceous shale formations miss homogeneity in fact by almost as much as the geologic column of California misses it.

If it be granted, however, that some facies may exist the study of which would throw sufficient light on the conditions of origin of the formation as a whole, there still remains the difficulty that nobody would be likely to begin his study of the formation by selecting such a facies. He can only select it at the conclusion of a successful study. If he does his selecting at the beginning, moreover, he has largely anticipated his conclusion, and thus has robbed it of most of its interest.

If these ideas are correct, the first step in developing a just idea of the sedimentational conditions of the Monterey shale seems to be to throw away all merely typical specimens. In their place one may then collect various unique or interesting specimens and study them as carefully as possible with reference to their character and associations. After numerous repetitions of the process, if good luck attends the effort, one may hope to see some general facts emerging on the basis of which, perhaps, a sedimentational hypothesis, or preferably several of them, may be constructed. Finally, typical specimens may be selected.

In accordance with this plan an attempt is made in the present paper to describe the petrology of a siliceous shale formation that is perhaps unique. It has little relation, at any rate, to those previously discussed in the literature, although it appears to be fairly important. The exposures chiefly studied are in the sea cliff at Malaga Cove, south of Redondo, in the northwest end of the San Pedro Hills. This locality is at the seaward edge of the Los Angeles Basin. The beds concerned have been referred by Kew to his Pico formation, the

type locality of which is in Pico Canyon, near Newhall, 40 miles farther north. In a recent paper, for example, Kew writes:

> The Pliocene series, represented in southern California by the Fernando group, is in the San Pedro Hills divided into the Pico and Saugus formations, which are exposed along the foothills of the northeast side. The Pico, or lower Pliocene, consists of diatomaceous shale at its base grading upward into fine, sandy shales. It is this formation in which the best oil horizons of the Los Angeles Basin occur. The Saugus formation (upper Pliocene and early Pleistocene) is composed largely of medium grained fossiliferous sandstone with some conglomerate and shale, and is best shown on Deadman Island.[1]

With the reference of these beds to the Pico, Mr. D. D. Hughes, who kindly examined a few foraminiferal samples collected at Malaga Cove, is in substantial agreement. The fauna is very rich, and while it has not yet been studied intensively, Mr. Hughes states that it contains a typical "Lower Pico" assemblage, similar to that of the Los Angeles Basin oil horizons mentioned in the preceding quotation. The absence of this fauna from the Pico Canyon beds, however, and some other facts about its distribution, lead, in Mr. Hughes' opinion, to uncertainty as to its Miocene or Pliocene age. But however the broader correlation problem may be decided, there seems no reason to doubt the equivalence of the Malaga Cove rocks and the petroliferous strata of Signal Hill, Santa Fe Springs, and several other Los Angeles Basin oil fields. The fact that a formation of such great economic importance is beautifully exposed a few miles away from some of the areas in which it produces oil is relied upon to render interesting the following results of some rather desultory petrologic studies.

The exposures have been examined many times in the field. Large and small samples have been collected, and many of them subjected to microscopic study. A binocular microscope has been constantly used in examining the larger features, such as the bedding, texture, Foraminifera, etc. Many samples have been broken down in various ways, as by soaking in water, and examined under a polarizing microscope. In studying the very fine débris a biological microscope, giving magnifications of from 500 to 1,000 diameters with good illumination, was of great assistance. Owing to lack of

[1] W. S. W. Kew, "Geologic and Physiographic Features in the San Pedro Hills, Los Angeles County, California," *Oil Bulletin*, Vol. XII, No. 5 (1926), p. 513.

facilities I have been able to make only a few simple chemical tests. Mineralogical identifications rest largely on the determination of refractive indices by immersion in a series of oils.

STRUCTURE AND STRATIGRAPHY

The structure of the beds exposed at Malaga Cove is so complicated that even with the excellent exposures furnished by a high sea cliff, a good many points are far from obvious. In general, however, the pre-Pleistocene strata may be divided into three groups:

1. Cherty shale with many beds and lenses of secondary limestone. These are generally mapped as the Modelo formation, and considered Middle or Upper Miocene in age. They are not further discussed in this paper.

2. "Diatomaceous" shale, light-gray to dark-gray in color, thin-bedded (Fig. 1), with very few calcareous Foraminifera, but with some beds and nodules of limestone that may have been derived from Foraminifera. Some of this shale shows an alternation of whitish and dark-gray thin beds, which are remarkably brecciated (Fig. 2, and page 347).

3. Near the top of the exposed section is a 50-foot bed containing very abundant calcareous Foraminifera. This material is dark greenish-gray in color, somewhat brittle, and so poorly bedded that the structure is made evident only by the attitude of a few thin streaks of pure white volcanic ash. Overlying the foraminiferal rock is a small thickness of non-foraminiferal siliceous shale, not carefully examined.

THE NON-FORAMINIFERAL SILICEOUS SHALE

This shale is composed of thin streaks of lighter and darker material (Fig. 1), with rare streaks of volcanic ash, and occasional horizons of calcareous concretions. The remarkable brecciation which affects a part of this member will be treated on a later page. Though ashy gray along the coast, and nearly black where it is kept moist by the spray, this rock is whitish near the tops of the cliffs, and where exposed farther back does not differ noticeably from the usual soft "diatomite" of many localities in the Coast Ranges. The wet rock is more easily cut with a knife or an ax than

broken with a hammer. When thoroughly dried, the material is so porous that it effervesces on being placed in water.

I. MINERALS

On agitation with water the shale breaks down into a black mud from which the detrital minerals may be panned. They amount to

FIG. 1.—Normal, unbrecciated siliceous shale, Malaga Cove. The joints of the measuring stick are each one foot long.

not more than a few per cent of the total. A cubic inch or so of the material commonly gives enough grains for four or five slides.

Fragments of fresh volcanic glass are nearly always conspicuous, in some cases making about 30 per cent of all the detrital material.

The refractive index of several grains was determined and was found to vary from below 1.49 to about 1.503. Quartz and feldspar are more abundant than any other material except glass. Much of the feldspar is striated, the refractive indexes being sometimes a little above, at other times a little below, that of quartz, but always relatively near it. Some greenish chlorite grains occur, and rare flakes of brown biotite. Blue and green amphiboles are always present, but in very varying quantities. Glaucophane appears to be more abundant than crossite, but both were noted. Apatite, magnetite,

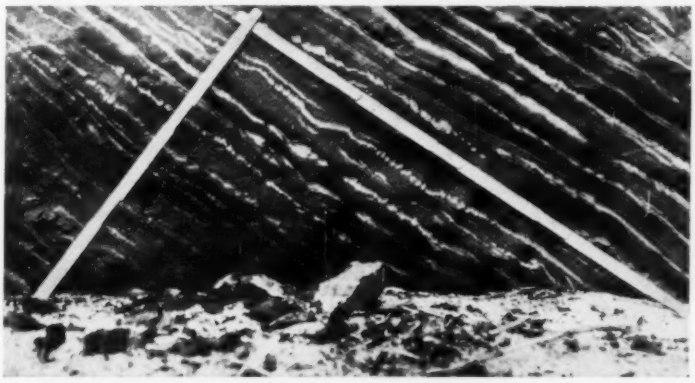

FIG. 2.—Brecciated shale, Malaga Cove. The measuring-stick in this picture has 8-inch joints.

and zircon occur in minor amounts. Occasional fragments of sponge spicules and some large subspherical Radiolaria were usually found in the panning concentrates. Epidote and garnet are absent from all the slides examined.

The majority of detrital grains are slightly above or below one-tenth millimeter in diameter, the volcanic glass fragments being the largest and the rare heavy minerals the smallest.

The only secondary minerals noted are glauconite and calcite. Chert is abundant in the beds classed as Miocene, and some may occur in the Lower Pico, but was not observed. The glauconite is found more abundantly in the foraminiferal beds, and will be discussed along with those beds. The calcite occurs in beds or nodular

lenses, one of which was studied in some detail. This nodule is situated just above the beach, and is enclosed in vertical shale beds. It shows an alternation of light-gray and dark-gray beds, the latter the thicker, all of which can be traced without change in thickness into the shale. Examination of the calcareous material and the equivalent shale in fragments failed to show the presence of Foraminifera. This test is decisive for the shale, which has only siliceous organisms; but the concretion had to be studied by additional methods. A thin section showed that calcified Radiolaria, sponge spicules, and diatoms are rather common. In some specimens the replacement appears to be complete; in others, only partial. Foraminifera are abundant, too, but are entirely recrystallized to granular calcite. The slide shows no glauconite, phosphate, or bituminous material.

The occurrence of altered Foraminifera in a limestone concretion which passes laterally into an unfossiliferous shale is interesting. It suggests the possibility that the shale was originally less barren of Foraminifera than at present, but all, or nearly all, have been leached out. When did the leaching occur? Since the lines of nodules are always parallel to the bedding, it would seem to have begun before the strata were notably arched. Perhaps the horizons where the concretions occur originally contained more Foraminifera than the rest of the formation, however, and thus caused the precipitation of calcite dissolved by ground waters from the less foraminiferal strata. On this supposition the leaching may or may not have begun early, but probably continued until recent times.[1] This subject is unfortunately too large and too complicated to be profitably discussed on the basis of so few observations.

II. ORGANISMS

A. FORAMINIFERA

Recognizable calcareous Foraminifera are very scarce in these beds. From a few thin streaks of the shale, samples have been collected that yielded a few specimens of perhaps a half-dozen species.

[1] For elaborate discussions of the possibilities that might be considered here, see L. Cayeux, "Contribution à l'étude micrographique des Roches Sédimentaires" (Lille, 1897), p. 443, and several other passages. Also, L. Cayeux, *Les Minerais de fer oolitique de France*, Part II (1922), p. 425.

The possibility that most of the forms originally present have been leached out since deposition is again suggested by some observations that may be recorded here. Many bedding planes of the barren shale show numerous small, white spots about the size and shape of a foraminifer. They are variously composed of small fragments of volcanic glass, of minute sponge spicules, or of sand grains. So far as observed, each spot has the majority of its mineral constituents of one kind. These spots, or at least most of them, are concluded to

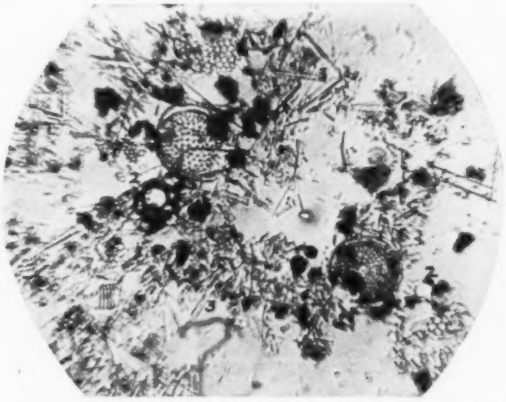

FIG. 3.—A strewn slide, from unbrecciated siliceous shale. There are some broken and unbroken diatoms (1), a few silicoflagellates large enough to show (2), and very numerous sponge spicules. (3), The dark splotches are pieces of the cement. Magnification approximately 300 diameters.

be arenaceous Foraminifera from which the calcareous cement has been leached.

B. SILICEOUS ORGANISMS

1. *Diatoms.*—Examination of samples with a hand lens often reveals the presence of some large disks which may be seen with higher magnification to be diatoms of the Coscinodiscus type (Fig. 3). The presence of these large diatoms is likely to lead to the erroneous opinion that the rock is composed almost exclusively of diatom débris. Diatoms are more abundant in some beds than in others, of course, but dominantly diatomaceous material is rather scarce. This statement seems to hold particularly well for the very

fine débris. Examination with high power shows the presence of occasional diatom fragments, including rare Coscinodiscus knobs, but most of the small fragments belong to other types of siliceous organisms. In nearly all the samples studied, in fact, both sponges and Radiolaria (including with the latter for the moment the Silicoflagellata) are more abundant than diatoms. This fact comes out clearly when a given slide is examined with successively higher powers of the miscroscope. The higher the power, the less conspicuous the diatom fragments become.

2. *Radiolaria and Silicoflagellata.*—Some of the Radiolaria are large and nearly as noticeable at low powers as the diatom disks. These are all Spherellaria. Higher magnifications show the presence of many smaller forms of the same kind, and also of some beautiful bell-shaped Nasselaria. The material composing them is clear, unaltered opal with refractive index lower than 1.47. Along with these forms there are many other organisms with opal tests which do not appear to belong to either legion of the Radiolaria. A slide containing these was submitted to Dr. G. D. Hanna, who refers them to the Silicoflagellata, some of the commoner genera being Distephanus, and Mesocena. With a magnification of about 500 diameters they are seen to be very abundant and of many different forms: ring-shaped, spiny-globose, and irregular. I have noted similar forms in a few samples of diatomaceous material from other areas, and suspect that they may constitute a considerable proportion of many of our organic shales. They apparently deserve to become better known among geologists.

Whenever it is subjected to a micropaleontological study, the Malaga Cove rock is sure to yield a large fauna both of Radiolaria and Silicoflagellata. Inasmuch as these organisms make up probably a third of many samples, this rock recalls the radiolarian earths of Barbados and Trinidad.

3. *Sponges.*—In a few places beds were observed in which sponge spicules are so abundant as to give the rock a felted appearance. In general, however, the proportion of sponge remains is about like that of the groups last discussed. In many samples the sponge remains are clearly more abundant than the diatomaceous material. The great majority of the spicules are beautifully preserved, but in a

few the canal is partly filled, or otherwise altered. The material is always opal, with refractive index below 1.47. The spicules vary enormously in shape and size, but nearly all may be derived from the Monactinellida. A few are certainly from the Tetractinellida, however, and one or two suggest Hexactinellida. A few aggregates recall the appearance of stony sponges (Lithistida), but they may be something else. On the whole, the most striking fact about the sponge remains is the great dominance of spicules of the monactinellid type.

Aside from a few fragments of bone and wood, no other organic remains have been seen in this rock.

III. CEMENT

As with other fine-grained rocks, the determination of the very small fragments is difficult, and the results are often unsatisfactory. Some mounts show a good deal of material that cannot be resolved with the high power of the petrographic microscope. Others show a yellowish cement inclosing myriads of fragments of siliceous organisms and rare grains of detrital minerals. Some of the clayey matter in a few specimens has the refractive index and general appearance of glauconite, but much of it is something else. In all samples there are occasional fragments of volcanic glass. The macroscopic appearance of the material had led to the suspicion that much of the clay material might be altered glass, but the microscope furnishes no good evidence in favor of it. The use of very high magnifications shows that much of the material at first classed as "clay" is composed of about the same constituents as the coarser fragments. A great deal of it is therefore opal; some of it, quartz and volcanic glass; some is chlorite; and the rest is of unknown character. Collophane was suspected in one or two slides, but its presence could not be demonstrated. Chert is abundant lower in the section, but in the shale here under discussion it is absent or nearly so.

IV. STRATIFICATION

The stratification of this rock shows several features that deserve notice. In the first place, the whole of the exposed material is thinly and uniformly bedded, the dark-gray beds being 1/2 inch in thickness, and the light-colored beds considerably thinner (Fig. 1).

Upon the dominant rhythm, however, smaller rhythms are likely to be superimposed. A dark-colored bed, in other words, often has several extremely thin but fairly persistent light-colored laminae within it. And even the thicker beds of light color may themselves be bedded. The type of bedding of this material is thus very similar to that of many Miocene formations of California, and of not a few Pliocene formations. Observations made upon a variety of thin-bedded formations have shown that commonly the thicker beds are coarser, such as sand or silt, while the thinner beds may be silt, clay, diatomite, sponge spicules, or the like. The base of the coarse bed often clearly represents a slight break in sedimentation. Very frequently the top of the layer of finest material contains practically all the recognizable organic material—diatoms, Foraminifera, etc.—in a given section.

An obvious explanation for the general condition is that the coarse material represents the rainy seasons on the adjacent lands, that the clay settled out when the floods subsided, and that the organic material accumulated between floods. This hypothesis is entirely inconsistent with present ideas concerning the rate of accumulation of sediments, however, or the rate of denudation of land areas. There is a possibility that the various kinds of evidence are capable of being harmonized, but the discussion would lead too far from the present subject.

The only material contained in the dark bands at Malaga Cove, which is noticeably darker or coarser than that in the light bands, is glauconite, and it is not abundant. Preparations from the two kinds of layers do not, in fact, differ very strikingly in microscopic appearance. When perfectly dry, the beds do not differ much in color, even to the naked eye. Thus the contrast that appears so striking in a cliff kept moist by the spray (Fig. 1) tends to disappear when examined closely. Further study is likely to show that the bedding of this rock resembles that of other siliceous formations in origin as well as in general appearance, but at present too many problems remain unsolved to make further discussion worth while.

Another striking feature is the brecciation that is beautifully developed in a part of the section (Fig. 2). Many of the thin, light-colored bands are broken into short, angular, or partly rounded

fragments and rotated so as to lie with a high angle to the bedding planes. In a few cases the planes of fracture separating the fragments extend into the adjacent dark-colored beds, but ordinarily the latter are continuous. Very often badly broken light-colored bands alternate with others that are unbroken. Some thin, hard, calcareous beds are similarly broken. In spite of the presence of some small secondary faults, it seems probable that most of these broken shale beds are properly classified as intraformational breccia. They were broken on the sea bottom, in this case, presumably by current or wave action, after deposition and slight hardening of the light-colored bands.[1] This feature has an interesting bearing on the question of the depth of water in which this radiolarian deposit accumulated.

FORAMINIFERAL ROCK

The word "shale," which is often misleading as a designation for the California siliceous rocks, is utterly so when applied to the foraminiferal horizon at Malaga Cove. The stratification is so poor that, as already noted, only the presence of occasional beds of volcanic glass makes the structure evident. The rock is nearly black when wet, and dark green when dry. Its specific gravity is noticeably higher than that of the associated siliceous shales.

The composition was estimated by examining crushed material and by panning and otherwise separating constituents. The figures derived from this study, which are intended only to approximate the truth, are as follows:

	Percentage
Detrital grains	20
Glauconite grains	5
Glauconitic clay, including some very minute siliceous fragments	55
Foraminifera, entire and broken	20
Echinoid spines and siliceous organisms	5

That the proportion of Foraminifera may have been underestimated is suggested by the fact that slightly more than 30 per cent of a sample dissolved in dilute hydrochloric acid.

[1] For an interesting case somewhat analogous to this, see L. Cayeux, *Les Minerais de fer oolitique de France*, Fascicule II (Paris, 1922), p. 931.

1. MINERALS

Examination with a hand lens reveals the presence of some mineral grains, especially rather large grains of chlorite. Screening shows that most of the grains other than chlorite and mica pass the 100-mesh sieve. The light minerals are quartz and feldspar in approximately equal amounts, the latter including a good deal of striated feldspar with indices near 1.545. Grains of volcanic glass are fairly common, but less so than in the more siliceous shale. The heavy minerals are conspicuously abundant, green hornblende being commonest. Glaucamphiboles occur, but are rare. Apatite is common, zircon fairly so, and magnetite present. A few grains, not carefully studied, appeared to be titanite. Neither epidote nor garnet has been seen in this rock.

The secondary minerals are glauconite and calcite, the latter occurring as before in the form of nodules. The glauconite occurs in grains and in the cement. The grains are much larger than the associated detrital minerals, and are generally larger than the Foraminifera. It is thus hard to believe that their entire growth took place inside foraminiferal shells, especially as no glauconite-filled shells have been seen. The smoothly rounded contours of the grains suggest, on the other hand, that they may have been generated at some distance from the final site of deposition, and rounded during transportation along the sea bottom.

On being crushed, the glauconite grains break into platy masses with refractive indices commonly, but not always, higher than 1.60. The lower indices may be due to some impurity, such as admixed collophane. The polarization is of the aggregate type.

A single calcareous nodule from this horizon was seen and studied by means of a thin section. Even under the hand lens this rock shows an abundance of well-preserved Foraminifera. A thin section shows many of them, some hollow, some filled with calcite, and others with a black, opaque substance supposed to be bitumen (Fig. 4). The calcite filling the cavities is granular and noticeably coarser than that of the matrix. A few areas are interpreted as calcified diatom or radiolarian tests, and one circular area of calcite with lines radiating from the center is doubtless the cross-section of an echinoid spine. In addition to the organic remains, the section

shows a good many small angular grains of quartz and feldspar, and several bright-green glauconite grains. This glauconite gives aggregate polarization and has a refractive index considerably higher than that of balsam. The grains are independent of Foraminifera. Several of them occur more or less in a straight line, possibly parallel

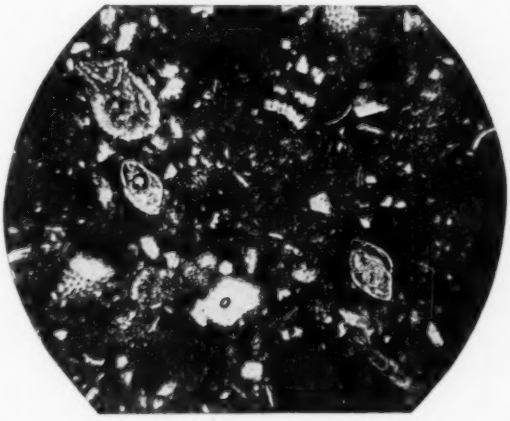

FIG. 4.—Thin section of limestone nodule from foraminiferal rock, in ordinary light. Three of the Foraminifera show a filling of black bitumen (?). There are also detrital grains, fragments of Foraminifera, some spotted areas that are either radiolaria or diatoms, and a matrix of granular calcite. The spot marked "o" is a hole in the slide. No glauconite shows in this particular field. Magnification approximately 60 diameters.

to the bedding, which was not evident in the nodule nor in the shale immediately surrounding it.

II. ORGANISMS

A. CALCAREOUS ORGANISMS

1. *Foraminifera.*—Foraminifera are not only abundant but very beautifully preserved. No better horizon for calcareous forms is known to the writer in California. The genera most abundantly represented are *Uvigerina*, *Nodosaria*, *Bulimina*, *Rotalia*, *Siphogenerina*, and a few others. Occasional specimens of many other genera occur, including very rare *Miliolidae*. This fauna well deserves a monographic study.

2. *Echinoid spines.*—These are common, but much less so than the Foraminifera. Those studied are made up of radiating plates, with interseptal tissue of a different texture and color. The whole spine appears to be calcite with unity of optical orientation. The spines are all straight, but vary greatly in surface ornamentation. One spine showed a pentagonal cross-section, the others studied being circular.

3. *Mollusks.*—As a rare exception, one pelecypod shell, of thin material and perhaps two inches long, was found imbedded in this rock. It was badly broken in the process of removal, and appears to be beyond identification. No other shells or even shell fragments occur anywhere in the exposed rock, and the inference seems justified that this one was transported by some unusual means from a more or less distant area and dropped into the organic ooze.

B. SILICEOUS ORGANISMS

The siliceous organisms, which have been estimated to constitute 5 per cent of the rock, with an unknown additional percentage in the very finest material, belong to the usual three groups—diatoms, Radiolaria (including Silicoflagellata), and sponges. Their relations in one slide were estimated as follows: diatoms, 25 per cent, Radiolaria, 35 per cent; sponge spicules, 40 per cent. The diatoms are chiefly large circular forms, and their fragments do not make up a conspicuous amount of the very finest material. The Radiolaria include both Spherellaria and Nasselaria, the former being the more abundant. Silicoflagellata are perhaps more abundant than either, at least in the very fine separates. The sponge spicules, like those in the non-calcareous shale, are dominantly monacts, with a very few belonging to the other orders. The spicules include a great many beautiful spinose individuals in addition to the more common smooth forms.

C. OTHER ORGANISMS

Other traces of organisms include fragments of bone and carbonized wood. As in the more siliceous rocks of this area, fish scales are very scarce.

III. CEMENT

The fine material includes a great many fragments of siliceous organisms and a considerable amount of glauconite. Chloritic ma-

terial doubtless occurs, but its presence is not easily demonstrated. Collophane was looked for, but not recognized. Minute flakes of the various detrital grains occur. Fragments of foraminiferal tests are abundant. Coccoliths and rhabdoliths were carefully searched for, but without success.

SUMMARY

The constituents of these two siliceous rocks are all the same, but they occur in very different proportions in the two. Thus the foraminiferal rock contains more glauconite, more detrital material, and more calcareous Foraminifera. Its siliceous organisms belong to the same groups as those of the shale, and are superficially very similar to them, but do not constitute nearly so large a part of the total. Volcanic ash occurs in rare beds in both rocks, and also distributed sparsely through them.

The age of the foraminiferal beds is known without doubt, and is Lower Pico; that of the siliceous rock is less definitely known, since Kew's reference of it to the Lower Pico appears to have been made without benefit of paleontology. So far as present purposes are concerned, however, the similarity so far demonstrated between the two is considered adequate grounds for studying them together. Even if they should be demonstrated to differ in age, they surely must have originated under somewhat similar conditions.

OTHER SOUTHERN CALIFORNIA SHALES

For purposes of comparison, brief descriptions of two shales from other parts of the Los Angeles Basin are inserted here.

1. *Lower Pico Shale from oil wells at Seal Beach.*—Associated with the oil sands at Seal Beach there are some bodies of shale which, as noted before, have the same foraminiferal fauna as the rock at Malaga Cove. According to the determinations of Dr. P. P. Goudkoff, the heavy minerals are also similar. A cursory examination shows, moreover, that this rock is composed dominantly of terrigenous material, with siliceous organisms present but rare. This shale is thus faunally and mineralogically equivalent to that at Malaga Cove, but represents a markedly different facies.

2. *Puente (Miocene) Diatomite from La Habra Canyon, Puente Hills.*—In some road cuts in the Puente Hills there are beautiful

exposures of white siliceous material which occurs in thin beds alternating with slightly thicker beds of well-sorted fine sand or silt. Some of the white beds are composed chiefly of diatom tests, while a few contain almost nothing but sponge spicules. No samples from this locality are dominantly radiolarian, but all contain some Radiolaria and some Silicoflagellata. The point to be noted is that Radiolaria are not uncommon in this rock which gives clear evidence of shallow-water deposition.

PALEOGEOGRAPHICAL DISCUSSION

The Malaga Cove rock has various characteristics that give some hint of the conditions under which it accumulated. These features will now be passed in review to see how well they can be made to agree.

Stratification and brecciation.—The stratification of most of the Malaga Cove siliceous shale is exactly like that of many California shales which can be shown to have accumulated in comparatively shallow water. If the brecciation found in a part of the shale is due to the rippling action of waves on a thin, slightly hardened bed at the bottom of the sea, then the depth was probably less than 100 fathoms. The possibility of other explanations cannot be excluded, however, simply because they have not yet been thought of, and one may yet be found that will be consistent with a greater depth.

Detrital grains.—The detrital grains tell us little about the depth of the water or other conditions of deposition. Their kinds show us, however, that they were derived, at least in large part, from Woodford's "western" land mass, of which Catalina Island is a small modern remnant.[1] Detritus derived from the highlands north of the Los Angeles Basin lacks glaucophane and is high in epidote and garnet, neither of which was observed in the Malaga Cove rocks.

Glauconite.—The abundance of glauconite, particularly in the foraminiferal rock, is one of its striking characteristics. This mineral is supposed to be formed where high and bold coasts face the sea, without large rivers; on the continental shelf or slope; where organic material is present on the bottom in just the right quantity; where neither the deltaic nor the pelagic type of deposition is active.

[1] A. O. Woodford, "The San Onofre Breccia," *University of California Publications in Geology*, Vol. XV (1925), pp. 159–280.

In his *Geologie des Meeresbodens*, Andrée states that the conditions near the 100-fathom line appear to be most favorable to glauconite formation, and recalls that nowhere have samples of such purity been dredged as along the California coast in depths of 200–700 meters (pp. 246, 248). The presence of glauconite in considerable abundance in the Malaga Cove rocks might thus be considered to indicate deposition in water from a few hundred to perhaps a few thousand feet deep.

Diatoms.—The evidence of the diatoms cannot be given because of lack of knowledge of the species present, or of their habits.

Radiolaria and Silicoflagellata.—If the statements of many textbooks concerning radiolarian rocks were true, the shales here under discussion would have to be considered deep-sea deposits. The *Treatise on Sedimentation*, for example, contains the following (p. 126): "The occurrence of radiolarian shells in significant quantities suggests depths of 12,000 to 25,000 feet." From similar reasoning the much-discussed Barbados radiolarian earth has often been considered a genuine example of a deep-sea ooze. A few recent students, such as Vaughan,[1] Walther,[2] Diener,[3] and De Lapparent,[4] dissent from this opinion, however, and hold that some radiolarian sediments, including the Barbados rock, are shallow-water deposits. The fact that some difference of opinion seems to exist on this point was the chief reason for introducing before a brief account of the La Habra Canyon "diatomite." Though containing many Radiolaria, this shale has numerous interbedded strata of fine sand, and must have been deposited at depths of 100 fathoms, or more probably much less.

The writer knows nothing of the bathymetric conditions that the Silicoflagellata may suggest.

Sponges.—The abundant sponge remains have been shown to be dominantly of monactinellid types, while the Hexactinellida are almost unrepresented. The Challenger data[5] show the latter to be

[1] T. Wayland Vaughan, personal communication.

[2] Johannes Walther, *Allgemeine Palaeontologie*, Vol. III, p. 473.

[3] C. Diener, *Grundzüge der Biostratigraphie*, p. 42.

[4] J. De Lapparent, *Leçons de Pétrographie*, p. 323.

[5] As summarized by Cayeux, *Introduction a l'Étude Pétrographique des Roches Sédimentaires*, p. 411.

absent from bottoms less than 93 meters deep, and dominant below 1,829 meters.

Foraminifera.—Whenever the Foraminifera are closely studied it may become possible to define the bathymetric conditions with fair precision. If some of the most abundant species are still living, and if the depths and bottom conditions which they prefer can be ascertained, it would seem possible to attain reasonable certainty. At present, however, it is necessary to approach a solution of the problem less directly. Many of the most abundant genera, for example, are at present similarly abundant in deposits collected at depths of 100–500 fathoms in the Philippine region.[1] Genera that are there characteristic of decidedly greater or lesser depths than those are either absent or much less well represented in the Malaga Cove deposits.

Echinoid spines.—The echinoid material is said to accumulate in deposits of practically all depths.

Summary.—On the whole, all the data seem to be consistent with the idea of deposition in water from a few hundred feet to a few hundred fathoms deep. There is no proof that the depth of the water was always the same. The foraminiferal rock has a more "littoral" aspect than the shale, and may, or may not, have accumulated in water of lesser depth.

THE MALAGA COVE ROCK AS A POSSIBLE OIL-GENERATOR

The relation of these rocks to the prolific oil sands of southern California suggests the possibility that they may have had something to do with the genesis of the oil. There are at present two chief theories as to the source of the oil in this region. The older theory assumes that the oil originated in "Miocene" diatomaceous shale and migrated upward across a profound unconformity into the reservoir rocks where we now find it. This view arose from studies in other parts of California, but has been vigorously upheld by many geologists as applicable to the accumulations under discussion here. Cunningham has criticized[2] the theory adversely on the ground,

[1] J. A. Cushman, "Foraminifera of the Philippine and Adjacent Seas," *U.S. Nat. Mus. Bull. 100* (1921).

[2] George M. Cunningham, "Were Diatoms the Chief Source of California Oil? *Bull. Amer. Assoc. Petrol. Geol.*, Vol. X (1926), p. 709.

among others, that in several southern California oil fields some thousands of feet of non-petroliferous "Pliocene" shale and sandstone lie between the producing horizons and the assumed "mother-rock." He suggests as more probable the theory that the oil may be derived from "the Pliocene shale bodies within the oil zones." The present study, which shows that the shale bodies in question appear to grade laterally within a few miles into highly organic shale, seems to me consistent with at least the major points in Cunningham's hypothesis. Because of the great complexity of this subject, however, no further discussion of it will be undertaken here.

SUMMARY OF CONCLUSIONS

1. The detrital minerals were derived from a "western" source, with rocks similar to those now exposed on Catalina Island.

2. Glauconite is abundant, particularly in the foraminiferal rock; but in origin it does not have any demonstrably close relation to the associated foraminiferal shells.

3. The calcite seems likely to be in part epigenetic, rather than entirely diagenetic.

4. Siliceous organisms make up a large proportion of the rock, with sponges, radiolarians, and silicoflagellates contending with the diatoms for supremacy.

5. The very fine débris contains several other constituents more conspicuously abundant than comminuted diatom débris.

6. Calcareous Foraminifera are extremely well represented in one of the facies studied; in the other they appear to have been leached out since the deposition of the rock.

7. The abundance and excellent preservation of many kinds of micro-organisms should make this rock a rich field for micropaleontological research.

8. The character of the rock and its paleontological equivalence to the Lower Pico of the oil fields bring up in an interesting way the possibility that it may have had a part in oil genesis. This possibility holds particularly for the foraminiferal facies, since there is still some doubt about the correlation of the other.

THE CENOZOIC HISTORY OF THE NORTHWEST PUNJAB

J. MARVIN WELLER[1]

ABSTRACT

Uplift of the Himalayas began at the end of the Mesozoic and has continued until recent times. Tertiary sediments accumulated in a trough along the southern mountain border in what was once the western extension of the Tethys. These sediments are marine at the base, followed by transition beds and a vast thickness of continental deposits. The Salt Range was initiated by an overthrust at the close of the Eocene. At the end of the Tertiary the sediment-filled trough was uplifted and greatly deformed and compressed. This was followed by very rapid peneplanation. Uplift of the Salt Range in Pleistocene times, probably accompanied by igneous intrusion, produced ponded conditions between it and the Himalayas. Important modification of the main drainage lines was produced when this barrier was cut through. Recent deformation in the Salt Range and along the Himalayas has resulted in folding and faulting of the Pleistocene sediments.

INTRODUCTION

The northwestern part of the Punjab in British India constitutes a distinct geologic and physiographic province sharply separated from the remainder of this region. The Salt Range rises abruptly from the Indo-Gangetic alluvial plain which separates the ancient positive element of the Indian peninsula from the Himalayas and forms the southern boundary of a great plateau area about 150 miles long and 60 miles wide. The geology of this area is fairly well known in a general way, having been first mapped by Wynn in 1877[2] and described in a memoir by Pascoe in 1920,[3] while numerous other authors have contributed papers. A review of the literature on Indian geology reveals that this area probably contains a greater variety of geological features than any other of equal size in this part of the British Empire. Although many of these features have been the basis of speculation or investigation from time to time, apparently no one has attempted to organize the information which is

[1] Published by permission of the Whitehall Petroleum Corp., Ltd., London.

[2] A. B. Wynn, "Notes on the Tertiary Zone and the Underlying Rocks in the North West Punjab," *Geol. Surv. Ind.*, Rec. 10 (1877).

[3] E. H. Pascoe, "Petroleum in the Punjab and North-West Frontier Province," *Geol. Surv. Ind.*, Mem. 40, Part III (1920).

available in such a manner as to outline the geological history of the area.

During part of 1920, 1921, and 1922 the writer was a member of a geological staff engaged in petroleum investigation in the northwest Punjab. Field work was conducted throughout the greater part of the plateau area as well as a portion of the Salt Range. This paper is not intended to be authoritative or final, but it is hoped that it may direct attention toward the interesting geological problems of the area and suggest certain conclusions concerning the geological history and development of this part of India. The private nature of the writer's work renders it necessary to omit mention of most details, and the generalized scope of this paper prohibits the description of situations of local interest.

TOPOGRAPHY

The Indo-Gangetic alluvial plain is a flat expanse of featureless, arid country with an average elevation of about 625 feet above the sea. Above this low-lying area, the Salt Range rises abruptly to an average elevation of about 3,000 feet and reaches its highest point at Mount Sakesar some 5,000 feet above the sea. This range varies in width from 1 to 15 miles and is greatly dissected by erosion, but in its wider part it is formed of a series of broad, parallel ridges and valleys. The outer flank is very sharp with a profile at many places of 45°. The northern flank is also much dissected and descends in the course of about 5 miles to an average elevation of about 2,000 feet upon the borders of the plateau area. This region, which is known as the Rawalpindi, or Potwar Plateau, slopes gently to the north toward the Soan River, descending to an average elevation of about 1,200 feet in 25 miles. North of the Soan River the plateau surface rises about 200 feet in 25 miles to the outermost foothills of the Himalayas.

The Rawalpindi Plateau is a typical semiarid region of nearly flat uplands and narrow, deeply intrenched stream courses which are dry the greater part of the year. The uplands are interrupted here and there by narrow hogbacks formed by resistant strata. In certain area, where the beds are easily eroded, bad-land topography has been developed on a large scale.

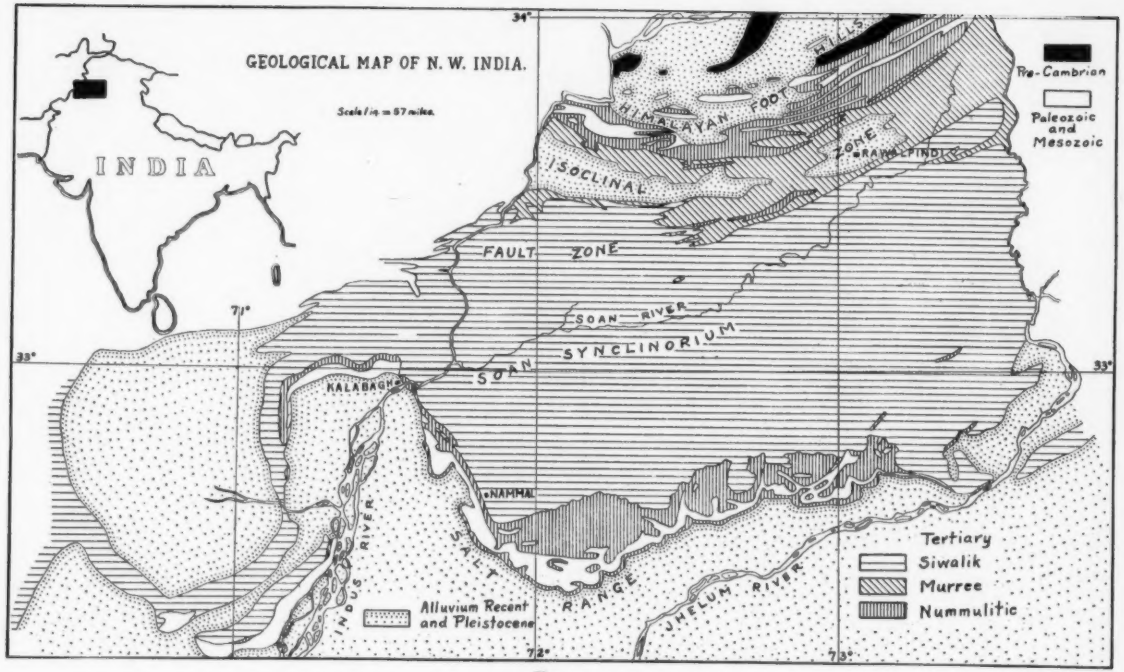
GEOLOGICAL MAP OF N. W. INDIA.
Scale 1 in. = 67 miles.
INDIA
34°
33°
71°
72°
73°
HILLS
HIMALAYAN FOOT ZONE
RAWALPINDI
ISOCLINAL
FAULT ZONE
SOAN RIVER
SOAN SYNCLINORIUM
KALABAGH
NAMMAL
SALT RANGE
INDUS RIVER
JHELUM RIVER
Pre-Cambrian
Paleozoic and Mesozoic
Tertiary
Siwalik
Murree
Nummulitic
Alluvium Recent and Pleistocene

FIG. 1

STRATIGRAPHY

A metamorphic series of slates and schists outcrops in the Himalayan foothills near the Indus River. It is at least as old as Lower Cambrian and probably older.

Sandstones, shales, and limestones containing Lower Cambrian fossils occur in the Salt Range. These are succeeded by Upper Carboniferous beds consisting of limestone, sandstone, and tillite, attaining a thickness in some places of 750 feet. Above the Permian limestone occur beds of Triassic, Jurassic, and Cretaceous age, with an aggregate thickness of about 700 feet.

The beds of greatest development in Northwestern India are the Tertiaries, which are here divided into three series. The lowermost, or Nummulitic series of Eocene age, is extensively exposed in the Salt Range and Himalayan foothills. The Murree series is absent from the Salt Range region, but attains a great thickness in the hills to the north. The Siwalik series, which extends into the uppermost Pliocene, occupies most of the plateau area.

The Nummulitic beds are separated into an upper and a lower part, each of which is again subdivided. The Lower Nummulitic consists mainly of massively bedded, light-gray limestone which is quite cherty in some parts and attains a maximum thickness of over 1,500 feet. The Upper Nummulitic is composed of a series of variegated shales and interbedded limestones and reaches a maximum thickness of similar proportions.

The Murree series is composed of alternating highly colored clays and sandstones which possess a characteristic maroon to purple color and is of fresh-water origin. It attains a thickness of over 7,000 feet in the Murree Hills.

The Siwalik series is similar in general character to the Murree. The sandstones are usually various shades of gray, and the clays are maroon and purple in the lower portion, become brilliant reds at higher horizons, and then fade out to buffs and drabs. Conglomerate beds are characteristic of the upper part of the series. The pebbles and boulders attain a maximum size of about 18 inches in diameter and occur in beds of as much as 300 feet in thickness. Many of them have a faceted appearance and were probably derived from mountain glaciers. The greatest section of the Siwalik series measured by the writer was 16,500 feet.

Unconsolidated beds of more recent age, probably Pleistocene, are widely, although irregularly, present throughout the plateau area and also at considerably higher elevations in the Salt Range. They consist largely of drab silts but contain interbedded layers of conglomerate and calcareous tufa.

STRUCTURE

Structurally, the region between the Himalayan foothills and the Salt Range may be subdivided into four zones. The most northerly of these, characterized by vertical or steeply northward-dipping beds, has been termed the "isoclinal zone." The structure is highly

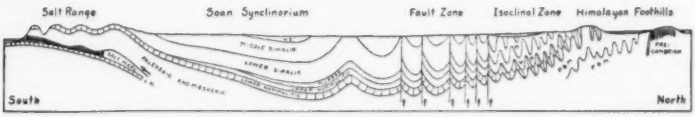

FIG. 2.—Cross-section of the plateau region of N.W. India

complex, being a series of tightly squeezed folds and overthrusts in which displacement has taken place chiefly along bedding planes.

To the south this belt merges into the fault zone. Numerous broad, open synclines are present, but the intervening anticlinal axes have been tightly squeezed, and stratigraphic displacement of as much as 10,000 feet in some cases has taken place along thrust faults which emerge parallel to the vertical bedding.

South of the fault zone occurs the Soan synclinorium which occupies nearly one-half of the plateau area east of the Indus River. This general synclinal structure is interrupted at many places by smaller and somewhat irregular folds which decrease in magnitude from either side as the axis of the major structure is approached.

The southern flank of the Soan synclinorium rises into the Salt Range monocline. An interesting although local feature of this structure is a group of underthrust faults of comparatively small dimensions which dip steeply to the southward.

GEOLOGICAL HISTORY

Late Mesozoic.—Toward the close of the Mesozoic era, the western arm of the Tethys Sea extended through Persia, Baluchistan,

Northwestern India, and the Northern Himalayan region. At the end of the Cretaceous period uplift took place in the Himalayan area and the sea was largely drained from its western extension.

Nummulitic sedimentation.—In the comparatively narrow trough which then existed between the recently uplifted Himalayan area on the north and the Indian landmass upon the south accumulated lacustrine and fluviatile beds composed of variegated sandstones, carbonaceous and gypseous shales and coal, to a maximum thickness of 150 feet. The thickness and composition of these beds, as well as the character of those which succeeded them, show that the Himalayan area had been elevated to no great height, and it is probable that the clastic sediments at the base of the Tertiary were largely derived from the southern landmass.

An encroachment of the sea restored marine conditions in this trough, and a long, narrow gulf was formed extending from Baluchistan to Eastern Afghanistan and thence along the southern border of the Himalayan area as far as Naini Tal. In this gulf were deposited great thicknesses of massive limestone which is crowded in places with the tests of nummulites. Subsidence accompanied sedimentation, while minor uplifts occurred in the Himalayan region. As these uplifts assumed more important proportions, clastic sediments were brought down from the north and the Nummulitic limestone was succeeded by clays. There now followed an extended period of competition between subsidence and aggradation, and marine, lagoon, marsh, lacustrine, and fluviatile deposits succeeded one another in irregular order. One of the most interesting features of the Upper Nummulitic is the presence of salt beds of considerable thickness, most extensively developed west of the Indus River.

Close of Nummulitic.—The Nummulitic epoch was brought to a close by important deformative forces. The Himalayan area was uplifted and forced southward. An extensive low-angle thrust fault was developed which reached the surface a considerable distance in advance of the mountain front where the massive Nummulitic limestone was broken through. The northern portion of this formation was thrust forward and overran its southern continuation, the argillaceous Upper Nummulitic beds serving as a shearing zone over which it moved. The development of this low-angle thrust fault

originated the Salt Range at the time when the earliest important uplift of the Himalayas occurred, and since that time it has shared to a lesser degree in all of the periodic uplifts of the closely related northern region.

The foregoing, generally accepted account of the origin of the Salt Range is the most satisfactory means of explaining the red salt marl which occurs at the base of the section throughout the Salt Range, and is considered to be of Upper Nummulitic age. These beds are absent from the north flank of the range, having been removed by pre-Siwalik erosion, except for a few small blocks which were preserved by downfaulting, or as gouge along some of the other faults.

Murree sedimentation.—Into the much narrower trough which now existed between the uplifted Himalayan area and the newly formed Salt Range were washed clastic sediments in great abundance. These were derived both from the highlands upon the north and from the Salt Range to the south, the latter of which was almost completely denuded of the clastic Upper Nummulitic beds. It is probable that almost continuous, slow uplift took place along the Himalayas during this time, while depression continued throughout the trough at their southern foot. Drainage conditions in this trough seem to have been unstable, and lacustrine, marsh, and fluviatile conditions prevailed at various times and at various places.

Siwalik sedimentation.—By early Siwalik time conditions appear to have changed in two important respects from those which prevailed during Murree time. In the first place, sedimentation in the trough and erosion of the Salt Range had combined to overcome the confining influence of this structure, and Siwalik strata were subsequently deposited farther to the south upon the Lower Nummulitic limestone of the Salt Range with an unconformity which, at some places, is notably angular. In the second place, drainage conditions had become stabilized and, as suggested by Pascoe, a great river with tributaries, both from the highlands to the north and the old continental area to the south, probably flowed northwestward through the trough from Assam to Kohat and thence south to the Arabian Sea.

In the valley of this great river were deposited the Siwalik sedi-

ments derived largely from the Himalayan area to the north. Regular subsidence of the trough continued, allowing the accumulation of a vast thickness of strata. The Lower Siwalik sediments show no evidence of extensive diastrophism at the close of Murree time and overlie the Murree conformably where these beds are present. It seems probable that the uplift of the Himalayan region, which had been progressing more or less continuously since mid-Nummulitic time, became accelerated after the close of the Murree, and elevation gained steadily over erosion. This is suggested by the colors of the Siwalik beds, which range from maroon at the base to drab in the upper portion, as though sedimentation had become progressively more rapid thus allowing less time for oxidation. The extensive conglomerate beds of the Upper Siwalik also point toward this conclusion, these being the first deposits of their kind derived from the Himalayas. These conglomerates, occurring as they do in beds 300 feet thick and containing boulders 18 inches in diameter, certainly indicate close proximity to fairly high mountains. The great concentration of these conglomerates in the neighborhood of the Indus and Jhelum rivers is proof that these streams were in existence and very active in late Tertiary time, and their origins may actually date back to the close of the Mesozoic era.

Close of Tertiary.—The Tertiary was concluded by diastrophism on a large scale. The trough, which now contained in some places as much as 25,000 feet of Tertiary beds, was deformed by violent thrusting from the north. The strata were thrown into folds which were greatly compressed and faulted adjacent to the advancing Himalayan mountain front, the severity of the deformation dying out in a southerly direction. The Salt Range was broadly arched and lifted, and a corresponding trough which comprises the present Indo-Gangetic plain was formed along its southern foot.

The crustal shortening which was accomplished along the belt of Tertiary sediments cannot be estimated with any degree of accuracy, both on account of the very complicated folding of the isoclinal zone and the numerous thrust faults which are present here and also in the fault zone to the south. In most cases these faults represent not only great stratigraphic displacement, but also an unknown amount of movement along the bedding planes. It seems

probable, however, that 25 per cent is a conservative estimate of the shortening between the Himalayan foothills and the Salt Range. It is surprising that deformation on such a scale should produce no apparent metamorphism, but even in the tightly folded zone, the clays have developed no schistosity and the sandstones are no more firmly cemented than in the areas of more gently dipping beds.

The crustal shortening produced by the folding and faulting between the Himalayas and the Salt Range resulted in a general uplift of the plateau region as well as the formation of considerable areas raised to a great altitude. This transformation in a region which had long been one of subsidence and sedimentation was similar, although on a smaller scale, to that of the Appalachian trough. Such transformations constitute one of the most important objections to the doctrine of complete isostatic adjustment.

Post-Tertiary erosion.—The deformation at the close of the Tertiary was followed by a period of stability and quiet of sufficiently long duration to permit the development of a peneplain. Fully 20,000 feet of strata were removed from certain portions of the area, and the former rugged topography was transformed into a level expanse above which rose here and there low hogbacks formed by the more resistant sandstones.

The peneplanation of this region must have proceeded with extraordinary rapidity in view of the facts that beds of uppermost Pliocene age were involved and that the action was completed long ago. This is probably to be explained by the slight degree of consolidation of the beds and the great altitude produced by the post-Tertiary deformation. The great resistance to erosion offered by the Lower Nummulitic limestone during this time, which resulted in this formation rising abruptly by dip slopes above the peneplain cut upon the later Tertiary clastics, is evidence that this region was not one of great precipitation, as a humid climate would probably have produced notable solution of the limestone. It is likely that seasonal periods of heavy rainfall were separated by longer periods of drought. Under such conditions little vegetation would have been present to protect the surface and the precipitation, although moderate when considered on an annual basis, might have produced a maximum amount of erosion.

It is probable that the Salt Range stood slightly above the level of this peneplain, being protected by the massive Nummulitic limestone which had been laid bare by erosion. The Indus seems to have occupied a valley at this time which crossed the low divide of the Salt Range at Nammal where to this day the barrier is notably constricted, being scarcely more than a mile in width. The Jhelum probably flowed down the present Soan Valley and joined the Indus north of the Salt Range.

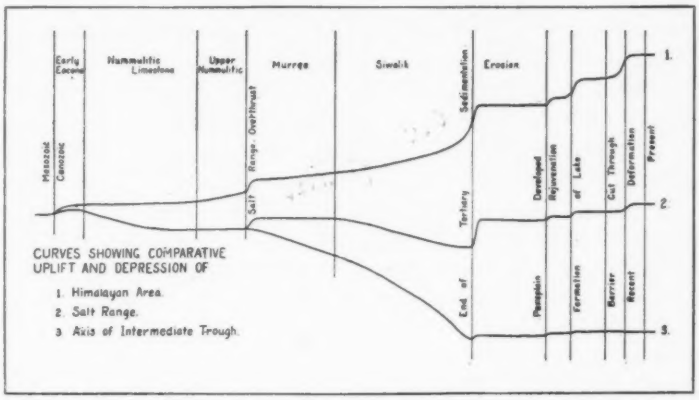

FIG. 3

A large part of the material removed from the area of the present plateau region may have been carried into the newly formed trough to the south of the Salt Range, which is still a belt of active aggradation.

Uplift and erosion.—A slight regional uplift of the plateau area to the extent of a few hundred feet rejuvenated the streams, and they intrenched themselves below the peneplain surface. They cut steep-walled, narrow valleys essentially similar to those occupied by the streams today, and only under exceptional circumstances were wider areas eroded to the levels of the valleys. The topography thus produced did not progress beyond the youthful stage, and in its characters reflected the dominance of a semiarid climate similar to that which prevails at present in this region.

Uplift of Salt Range.—Renewed thrusting from the north resulted in regional warpings which followed in a general manner the old structural lines. The Salt Range was arched up gently throughout its whole extent, and now stood considerably above the slightly depressed Soan synclinorium to the north and the more notably downwarped trough upon the south.

Pleistocene Lake.—The arching of the Salt Range proceeded with sufficient celerity to overcome the erosive power of the Indus, and a dam was formed behind which the waters collected in a great lake covering a considerable portion of the plateau region. Sediments carried in by the Indus and Jhelum rivers obliterated the former drainage lines, and are to be seen today as well-stratified silts with here and there layers of hard conglomerate. These conglomerates are particularly well developed along the flank of the Salt Range near Nammal, and probably mark the ancient course of the Indus.

Associated with the lake beds, particularly in the northwestern portion of the plateau, are erratic blocks of crystalline and metamorphic rocks, some of them of truly enormous size, whose present situations can hardly be explained without the transporting agency of floating ice.

The upbowing of the Salt Range may have been associated with igneous intrusion, basic rock being reported from one locality, but in any case numerous hot springs burst forth from the Nummulitic limestone along the Salt Range and the Himalayan foothills, and gave rise to great deposits of calcareous tufa. Their volume must have been very great, for ravines which had previously been eroded in the north flank of the Salt Range were in places completely filled up with this material and beds of tufa are locally present miles from the Nummulitic outcrop. Puny descendants of these springs are still active at a few places, as west of Nammal and at one locality in the trans-Indus salt region. The water issuing from these is, at the present time, strongly sulphureted and warm, and contains large quantities of calcium carbonate which is being deposited adjacent to their orifices. Blocks of this tufa were formerly quarried for building purposes and were extensively used in the ancient Buddhist city of Taxilla, located some 15 miles northwest of Rawalpindi, which has been excavated by the government, and also at a ruin in the Salt

Range which may have been the temple of fire visited by Alexander the Great during his conquest of the East.

The lake silts and associated beds of the plateau region are considered Pleistocene in age, and are probably to be correlated with the heavy, consolidated gravel and boulder terraces which are to be seen along the narrow Jhelum Valley at many places well back in the mountains on the road to the Kashmir Valley.

Drainage changes.—The dammed backwaters of the Indus and Jhelum rivers rose to the lowest points along the crest of the recently upraised Salt Range and spilled over to the south. The old courses of these rivers were abandoned, and the Indus began cutting for itself a narrow gorge at Kalabagh, while the Jhelum selected the route which it now follows. The gorge by means of which the Indus crosses the Salt Range is strongly in contrast with portions of its valley to the north, both on account of its younger age and the more resistant beds in which it is intrenched.

The establishment of these new outlets across the Salt Range served to initiate a new cycle of erosion. The lake was drained and a new drainage system was developed. It is uncertain to what extent the new valleys were intrenched below the bed of the old lake, but their courses as we see them today were determined at this time. To a considerable extent they follow the pre-lake drainage lines, and in many cases may have done little more than remove the silts from the old courses, but here and there the present valleys may be seen to leave their predecessors and follow new routes cut deeply into the Tertiary strata. Where this situation occurs, the valleys become notably constricted and in many cases the old silt-filled channels may be seen in the walls of the present valleys leading away to one side.

Recent deformation.—Thrusting forces again became active in comparatively recent times, the most important result of which was a considerable uplift of the Salt Range accompanied by faulting. In the vicinity of Nammal the lake beds, including notable deposits of gravel, are inclined to an angle of 15° or more, and in the adjacent portion of the Salt Range stratified silts occur at considerably greater elevations, while east of Mount Sakesar completely unconsolidated beds are faulted and dip at angles as great as 45°. Consider-

able movement also occurred along the foothills of the Himalayas, as north of Rawalpindi a bed of Pleistocene conglomerate stands in a vertical position.

While deformation occurred at this time both along the northern and southern borders of the plateau area, the intermediate region was unaffected unless regional uplift took place to a small degree. These movements were probably less rapid, although perhaps greater in their total effect, than those which preceded them, for, throughout their duration, the Indus and one or two smaller streams were able to maintain their courses by the downcutting of their channels, and no repetition of the Pleistocene ponded conditions occurred.

Present situation.—Dissection of the somewhat uplifted plateau area was accelerated by the latest movements, and is still proceeding along the tributary valleys. The main valleys have, however, been reduced to grade, and aggradation together with lateral widening is now taking place.

The plateau area of the northwest Punjab is a typical semiarid region and greatly resembles certain portions of Southwestern United States. Every small shower drains off quickly and collects as muddy torrents in the larger valleys which are ordinarily dry expanses of sand. Not only the character of the surface, which is almost totally unprotected by vegetation, but also the appearance of the occasional flood waters, makes erosion seem to be very active, but a closer scrutiny of individual situations shows that the effect produced over a considerable period of years is rather insignificant. A slow-growing desert tree, nearly a foot in diameter, rising from the lower portion of a valley slope not over a yard from a vertical bank of unconsolidated silt 12 or 15 feet in height, may be cited in illustration of this point.

CONCLUSIONS

Since the beginning of Tertiary time, when the first uplift of the Himalayan region occurred, vast thicknesses of sediments have been deposited in a slowly sinking trough along the southern border of the mountains. The geologists of the Indian Geological Survey have developed a theory that this trough was always limited upon the north by a "boundary fault" along whose plane the mountain mass

had been thrust upward and outward. They believe that at various intervals new boundary faults were formed, each occupying a more southerly position than the previous ones, and thus they explain the banded outcrops of the strata along the mountain foot. An inspection of the geological map of Northwestern India shows that the Nummulitic limestone outcrops in the foothills up to a certain line and no farther; that the Murree beds outcrop in the foothills and the adjacent plateaus only up to a certain line some miles to the south of the former; while the Siwaliks are confined to the plateaus, their outcrop along the north also being represented by a fairly regular line.

If the theory of boundary faults is to be followed in this region, the southern flank of the Salt Range must be considered the current and most recent boundary fault which is limiting the present accumulation of sediments in the Indo-Gangetic trough. Its history, however, when compared to that of the the Himalayas, does not bear this out, for this low, outlying range is nearly as old as the parent-mountain area itself. The Salt Range appears to be the result of a low angle overthrust which was produced at the close of the Eocene, early in the history of the deformation of the great Himalayan area. Subsequent movements and crustal shortening have taken place in the border zone between the Salt Range overthrust and the northern mountains.

If the basins of Murree and Siwalik sedimentation were bounded upon the north by faults, they could not have been of the typical boundary type because they were developed after the Salt Range overthrust. The writer has crossed, at many places, the supposed positions of the boundary faults which were considered to have limited the sedimentary basins of these Tertiary series upon the north, but he has failed to observe any evidence of their actual existence. Such faults are, however, not necessary to produce the banded outcrops that occur, as this would be the natural configuration upon the northern flank of the general synclinal structure of the plateaus.

It seems likely that if diastrophism continues active in this region, another low-angle overthrust may be produced which will come to the surface farther to the south in the zone of recent sediments of the Indo-Gangetic trough, to be followed by folding and compression of the beds to the north of it.

REVIEWS

The Great Soil Groups of the World and Their Development. By K. D. GLINKA. Translated from the German by C. F. MARBUT. Ann Arbor, Mich.: Edwards Bros., 1927. Pp. 235.

To Dr. Marbut the scientific readers of this country owe a debt of gratitude for making readily available the material of this important work. Professor Glinka at the time of his recent death (October, 1927) was considered as the leader of the Russian school of Pedologists (soil scientists) who have formulated the modern ideas of soil genetics. To the geologists these ideas are particularly pertinent from the standpoint of sedimentation, katamorphism, and Pleistocene correlations.

Soil is looked upon as the product of the decomposition and alteration *in situ* of parent-material. Successive recognizable horizons in the vertical section constitute the "soil profile." The major horizons of this profile from the surface downward are designated by the letters A, B, and C.

In recent investigations the soil horizons are designated as follows: The letter A is used to designate the eluvial horizon, i.e., from which in the process of soil formation either by chemical or mechanical means more or less material has been removed. With the letter B the illuvial horizon is usually designated. This is the horizon into which material has been carried, chemically or mechanically. The parent rock beneath is designated by the letter C.

A young soil shows poorly developed horizons while a mature soil has them well developed. The A zone has been, and still is, popularly and properly known as "the soil" while the B zone has been known as the "subsoil." But the new usage sharpens the critical interpretation of the profile, and gives significance to the deeper-lying horizons.

In the morphology of the soil type (1) the climatic conditions of the locality, (2) the combined effect of moisture and heat, (3) the essential features of the vegetation, and (4) the character of the parent-rock all find expression. Of these the most important for soil classification is moisture (which is affected by topography, vegetation, material, etc.) while temperature is of only slightly less importance. Those soils formed in response to external conditions, as of heat, moisture, vegetation, are designated as "ektodynamomorphic." Those controlled dominantly by internal conditions, as of the characters of the parent-rock material, are

called "endodynamomorphic." The discussion brings out clearly the fact that the external conditions in a great many cases so predominate over the internal ones that the same type of soil is found on parent-materials of widely different composition. The endodynamomorphic soils, also, are transitory bodies and are eventually and inevitably changed into ektodynamomorphic soils.

Glinka's classification of soils is as follows:

I. EKTODYNAMOMORPHIC SOILS

1. Soils developed under optimum moisture conditions
   a) Laterite
   b) Terra-Rossa
   c) Yellow soils
2. Soils developed under average moisture conditions
   a) Podsol (ashen-gray soils, particularly in the A_2 horizon)
   b) Gray forest soils
   c) Degraded tschermosem (forest cover alteration)
3. Soils developed under moderate moisture conditions
   a) Tschermosem (and Regur?) (very dark "A")
4. Soils developed under insufficient moisture conditions
   Group A:
   a) Chestnut-colored soils
   b) Brown soils
   c) Gray soils
   d) Red soils
   Group B:
   a) The brown crusts
   b) The lime crusts
   c) The gypsum crusts
5. Soils developed under excessive moisture conditions
   Group A:
   a) Moor soils (peat and muck soils)
   Group B:
   a) Soils of mountain meadows
   b) Peat soils of the dry tundras and mountain peaks
6. Soils developed under temporarily excessive moisture conditions
   a) Solonetz soils
   b) Solontschak soils
   c) Transition from *a*
   d) Transition from *b*

II. ENDODYNAMOMORPHIC SOILS

a) Rendzina
b) Various skeleton soils

It is obvious that a secondary basis of subgrouping must be made, as illustrated below:

Type of Soil	Varieties according to Petrographic Composition	Varieties according to Mechanical Composition
Tschermosem.....	Tschermosem from loess	Argillaceous Tschermosem
	Tschermosem from granite	Loamy Tschermosem
	Tschermosem from basalt	Sandy loam Tschermosem
	etc.	Sand Tschermosem
Podsol.....	Podsol on bowlder clay	Clay podsol
	Podsol on loess	Loam podsol
	Podsol on granite	Sandy loam podsol
	etc.	Sand podsol

We regard all soils, whose type characteristics have been determined by the character of the processes that have acted upon them as belonging to the same type, regardless of the petrographic or mechanical composition of the parent rock from which they have been derived.

Since in Europe temperature and rainfall both decrease in general in a northerly direction, the major soil types are found in broad northeast to southwest belts. While in North America, as pointed out by Marbut, the situation is more complex, for while the temperature decreases from south to north, the rainfall, generally speaking, decreases from east to west across the continent. This produces conditions unmatched in Europe and adds complexity to American classification.

After a comprehensive Introduction the author considers in detail the various types of soils given in his classification. His treatment of each type is arranged according to the historical development of the subject rather than to a clear statement of the present ideas of genesis. As a consequence the reader must study carefully to catch the significant points. The statements are all supported by abundant evidence, citations, and many chemical and mechanical analyses, so that the presentation is convincing. The profiles and certain characteristics of the main types may be given.

Laterite.—Hard though sectile mass, usually loamy, of brown, yellow, red, or white color. The light-colored and white spots are soft and on that account are washed out of the mass in exposed places—giving a honeycombed or cellular character. The percent of metallic iron varies from 25 to 36. The thickness of the soil layer is often very great, reaching a maximum of ten and occasionally hundreds of feet.

Typical Profile:

1. Dark-red laterite, 1 meter
2. Soft loose material rich in iron, 3 meters
3. Reddish compact material with yellowish streak, 1 meter

4. Yellowish material with whitish streak, 1 meter
5. Yellowish material containing grains of quartz, 1 meter
6. Slightly weathered gneiss, 1 meter

This soil is the result of the energetic hydrolysis of the minerals due to the high temperature and the presence of CO_2 resulting from the decomposition of organic matter.

Podsol.—The ash-gray color is the characteristic feature, particularly in the "A_2" horizon.

Typical profile of clayey podsol:

A. Whitish-gray, fine-grained layer, 5–6 inches thick
A_2. The podsolized horizon, nearly white fine powder, 5–6 inches thick
B. Compact clay mass, 8 inches
C. Compact bowlder clay, reddish brown in color

Podsolization is the process of producing the ashen-gray material in the soil profile.

Tschermosem.—The black-earth soils.

Profile:

A_1. Humus zone, very dark, faintly granular (10–14 inches)
A_2. Humus zone, very dark, 6–10 per cent humus, granular (14–18 inches)
B. Compact horizon (10–13 inches)

Chestnut-colored soils.—Dark-brown humus horizon.

Profile:

A_1. Brown color, laminated, relatively loose, 5–7 cm. thick
A_2. Lighter color, compact, 60 cm. thick. Effervesces in acid in lower part of A, or at the surface.
B. Compact horizon

Brown earth and gray earth are like the chestnut-colored soils but formed under conditions of better drainage.

Desert crusts.—Lime, and gypsum. Brown protective crusts. Turgite, goethite, pyrolusite. Capillarity and evaporation at surface of the rock.

Moor soils.—Moor, muck, and meadow soils.

A. Dark, undecomposed vegetation often darker in lower part. Thickness varies.
B. Exposed to percolating surface water and to rising ground water and formed under the influence of both is called the "glei" horizon, characterized by its bluish, light-blue, and greenish colors, due to the presence of vivianite. The prairies of North America along the Mississippi are of this type—20–30 cm. Where the ground water does not rise to the surface the glei is not developed. The mineralogy of the swamp soil is very complex and interesting due to the presence of sulphides, phosphates, etc.

Tundra soil.—Perpetually frozen subsoil.

Profile:

1. Grayish-brown humus horizon, 3 cm.
2. Yellowish-gray, loose loamy horizon, 2–3 cm.
3. Gray-blue horizon, very sticky loam, flows readily like fluid, 8–10 cm.
4. Brownish-yellow loam, 2–3 cm.
5. Compact horizon; at depth of 79 cm. from the surface the horizon is frozen.

Alkali soils.—"Solonetz" soils with sulphates and chlorides of calcium and sodium.

Profile:

A. Laminated, no effervescence, 30 cm.
B. Vertical cracks, no effervescence, 15–16 cm.
B_2. Compact, irregular cracks, effervesces, 19–20 cm.
C. Yellowish-gray loam, lime carbonate accumulation.

Solontschak are alkali soils in which the upper and lower humus horizons have the same development and are rich in soluble and sometimes insoluble salts. Occur within various soil zones and so may be designated by prefixing the zonal name to the soil name.

P. MACCLINTOCK

The Earth and Its History. By JOHN HODGDON BRADLEY, JR. Boston: Ginn & Co., 1928. 414 pages, 257 figs. $2.60.

This "elementary textbook of geology for use in a short course" is unique in arrangement of material. Outstanding is the regrouping of the classical trinity of processes into destruction, construction, and deformation, covered in chapters ii, iii, and iv, respectively.

The introductory chapter is much broader in scope than is usual. Exceptional material here treated includes the work and movements of the atmosphere; the movements of the sea water, including a discussion of waves; ground water, together with porosity and permeability of rocks; and the origin of continents and ocean basins.

Chapter v covers in order igneous, sedimentary, and metamorphic rocks, and structure. Historical geology is split in the two succeeding chapters into its physical and life-aspects, respectively. Thirty-six pages are given to the Archeozoic and succeeding groups; fifteen of these are for the Paleozoic. The remaining two chapters deal with the history of geology (forty-three pages) and applied geology, and are followed by a ten-page Index.

The mode of treatment of processes, combined with the scope of the

first chapter, has in certain cases resulted in a good deal of repetition. Many consider that such emphasis is needed, however. Destruction in one area, combined with transportation, means construction elsewhere, given time; the one necessarily leads to the other. While intergradation seems to be a general condition in nature, degradation and aggradation are particularly difficult to distinguish in the ultimate. Thus the author includes "flood plains" under the latter heading. But in general the deposits of the flood plain constitute but a veneer on the floor of the valley carved out by the removal of many times as much material. Production of mantle rock, and particularly the formation of terraces, seem entirely out of place under "construction."

One wonders why most of the general textbooks, although including discussions of open and closed, isoclinal, and recumbent folds, yet omit consideration of the salt dome as a structural feature. The book gives only the briefest description of a few rock-forming minerals (hardness is not mentioned), but covers igneous rocks in more detail than is usual in such works. Basalts are stated to be the extrusive equivalents of diorites and gabbros, although andesites are also described. Most gabbros are considerably lower in silica than is the average diorite. In skimming the book the reviewer noted some two-score places where rather minor errors of this type appear. Thus Figure 178 shows the coals in North Carolina and eastern Virginia to be of Pennsylvanian age. Coal is described as a sedimentary rock, and elsewhere (p. 35) it is stated that "sedimentary rocks are always secondary in origin." Only the humic coals are taken up under "carbonaceous deposits"; the several types of carbonaceous shales as well as asphaltic deposits are omitted. Coal is described with the Lower Cretaceous, but is not mentioned under Upper Cretaceous. "Petroleum is today the most valuable of hydrocarbons." Statements made regarding source rocks are too sweeping. Writing of the Lake Superior deposits, the author states (p. 246): "As was the case with the Middle Proterozoic iron formations, the copper was redistributed and concentrated by underground water." Figure 176 seems misleading in regard to depth of water above geosynclines. Only two pages are given to the physical history of the Pleistocene, and but twice as much to the life of the Quaternary (including man). Following general practice in elementary texts, there is no bibliography. An out-of-date conception of the spiral nebulae is presented.

Probably only those who have made the attempt fully appreciate the difficulties that beset the writer of the general textbook. In part this is because order and length of treatment of the various phases of the sub-

ject are matters largely of individual opinion and experience. In reviewing such a work, one tends to be on the *qui vive* for possible faults. One of the outstanding features of the book under review is its style. The reviewer believes that the author has been very successful in his "endeavor . . . . to make the presentation vivid where vividness is compatible with truth"; for instance: "On this threefold basis of inferential fact many diverse theories to account for the cause of vulcanism have been erected as targets, all of which have been riddled by a fusillade of criticism." In one case the author has possibly gone too far: "The earth . . . . is but . . . . a negligible quantity in the cosmos as a whole."

The chapter on applied geology is, except in a few minor details, quite outstanding. The preceding chapter on the history of geology, while exceptional in such a book, is nevertheless an excellent and very complete treatment. The general use of "fluid" or "liquid" rather than "melt" (unfortunately used at least twice) in referring to the magma is to be commended. With very few exceptions the photographs and diagrams set a high standard. The excellent physical appearance of the book is what is expected of the publishers, and only two or three minor errors of a typographical nature were noted: for example, "pitch" in the Index appears as "plunge" in the text. The book will have a very strong appeal to those teachers of a short course in general geology who agree with Professor Bradley's ideas of the order of treatment of the geologic processes, and any course in general geology will be enriched by using the material in the last two or three chapters for collateral reading.

D. J. FISHER

Over de samenstelling en het ontstaan van krijt- en mergelgesteenten van de Molukken (*On the Composition and the Origin of Chalks and Marls of the Moluccas*). By TAN SIN HOK. *Jaarboek v. h. Mijnwezen in Nederlandsch Oost-Indie*, 1926. Verhandel III. The Hague, 1927. Pp. 165; plates 16; figs. 2.

Chalks and marls of young Tertiary, probably Pliocene, age, collected by Dr. R. D. M. Verbeek (1898–99), of the first Netherlands Timor-Expedition (1910–12), and by Professor Dr. H. A. Brouwer (1915) were examined petrographically and paleontologically.

Paleontological results.—Stellate and rosette-shaped bodies of aragonite are supposed to belong to planctonic organisms; they are brought into a new group: *Discoasteridae incertae sedis*, in which the following genera are distinguished: *Heliodiscoaster*, *Eudiscoaster*, and *Hemidiscoas-*

ter. The discoaster fauna of the Moluccas shows rather great differences from that of Barbados.

Among the *Coccolithophoridae*, the coccoliths predominate, whereas the rhabdoliths are subordinate. The greater part of the foraminifera found are pelagic, the benthonic foraminifera are very subordinate.

The radiolarian fauna of Rotti was amply treated; 4 new genera were found, viz., *Cenolarcopyle*, *Hemicryptocapsa*, *Stylocryptocapsa*, and *Holocryptocapsa;* descriptions of 141 species eventually varieties, of which 138 are new, are given. The number of the radiolarian families found is small, but some of the families, as *Cyrtocalpida*, *Theocyrtida*, and *Lithocampida*, are very rich in species. Haeckel's systematical principles were followed rigorously, notwithstanding the author's opinion that the smaller categories, as genus and species, were founded on too detailed differences. In following the system of Haeckel, the student of a radiolarian fauna is certain to be forced to create many species.

The Cyrtoidea found belong mostly to the *Corocyrtidae* (Popofsky), which are phylogenetically highest developed. Some Eucyrtida show structures which support the opinion of a periodical length-growth.

Both from deductive and inductive considerations the author cannot assign a stratigraphical value to the radiolaria.

Sediment-petrographical results.—The following groups were distinguished: globigerina-chalks (from Rendjuwa, Savu, Rotti, Timor, and Ambon), discoaster-coccolith-chalks (from Rotti and Timor), radiolaria-coccolith-chalks (from Rotti), globigerina-marls (from Jamdena and Halmaheira).

In the globigerina-chalks the pelagic foraminifera, chiefly the globigerina, predominate; the discoaster-coccolith-chalks are characterized by the absence of greater foraminifera; in the radiolaria-coccolith-chalks radiolaria occur exclusively, whereas the foraminifera are totally absent.

The components of the groundmass of the globigerina-chalks are calcite and aragonite grains and prisms, coccoliths, calcospherulites, discoasters, and volcanic minerals, mentioned in the order of their importance. The discoaster-coccolith-chalks are entirely composed of these same groundmass components. The groundmass of the radiolaria-coccolith-chalks consists of calcite and aragonite grains and prisms, coccoliths and volcanic ash, whereas discoasters and calcospherulites are entirely absent.

For the reconstruction of the environments of sedimentation great stress is laid on the properties of the sediments themselves, as the stratigraphic relations of these sediments were too little known. For determin-

ing the conditions under which these chalks were deposited the calcispherulites and the radiolaria were of great importance. The calcispherulites were considered as chemical precipitates brought in direct connection with (putrefying) planctonic organisms. Their presence as essential component in the globigerina-chalks was considered to indicate an origin in a warm, shallow sea. So to the globigerina-chalks, notwithstanding their resemblance to an abyssal ooze, an origin in a shallow sea was attributed. A paleogeographical reconstruction of this sea could not yet be given. The discoaster-coccolith-chalks were considered as the finer washing-products of these globigerina-chalks.

In connection with Haecker's opinion that the morphology of the radiolarian skeleton is influenced by the depth in which the organisms live, the radiolaria of Rotti were compared with each other in the thickness of the wall, in the length and in the breadth of their skeletons. The result was that the radiolaria-coccolith-chalks could be arranged in an undeniable sequence, from which some bathymetrical conclusions were drawn, which (as yet) cannot be but relative.

The attention is called to the morphology of the radiolaria in relation to the depth in which they live, and on the value of these organisms as bathymeters for the radiolarian cherts.

The study closes with an explanation of the technique of making the preparations, and with an appendix on the tuffs of Timor.

T. S. H.

Clay and Cement in South Australia. By R. LOCKHART JACK. Geological Survey of South Australia, Department of Mines, Bulletin No. 12. Adelaide, 1926. Pp. 120.

This report concerns the economic geology of the clay and cement-forming constituents in the territory around the city of Adelaide. Discussions of the effect of various chemical constituents upon the clay products and cement are given. The major part of the report is taken up by analyses of samples from the several localities, and by details of the distribution of the deposits.

C. C. B.